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MINUTES OF PROCEEDINGS

OF

THE INSTITUTION

OF

CIVIL ENGINEERS,

WITH

ABSTRACTS OF THE DISCUSSIONS.

VOL. XXXVII.

SESSION 1873-74.—PART I.

EDITED BY

JAMES FORREST, ASSOC. INST. C.E., SECRETARY.

INDEX, PAGE 381.

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Note.—"The Lighthouse at Gabo Island, referred to in errata at the back of contents of vol. xxxiii., is one that has been recently removed, and replaced by a high granite tower, with a catodioptric light of the first order, erected under the direction of Mr. W. W. Wardell, M. Inst. C.E."

THE

INSTITUTION

OF

CIVIL ENGINEERS.

SESSION 1873-74.—PART I.

November 11, 1873.

T. HAWKSLEY, President,
in the Chair.

It was announced that the Council, acting under the provisions of Sect. IV. of the Bye-Laws, had admitted the following Candidates as Students of the Institution:—Walter Young Armstrong, William Palliser Costobadie, Henry Tipping Crook, John George Cruickshank, William Bell Dawson, Thomas Edwards, Matthew Pratt Elliot, William Theodore Foxlee, William Bernard Godfrey, John Hunter, Herbert Dent Johnston, Henry Eugène MacMahon, Joseph John Mullaly, Thomas O'Hagan, Henry Clements Perram, George Bernard Reynolds, Charles Spencer Rolfe, Alexander Ward, and Nicholas Watts.

No. 1,369.—"On Modern Locomotives, designed with a view to Economy, Durability, and Facility of Repair; together with some particulars of the Duty performed, and of the Cost of Repairs."[1] By John Robinson, M. Inst. C.E.

Before entering into the details of the construction of modern locomotives, and their adaptation to the work required, the Author will shortly review the difference between the railways of the present day, and the traffic conveyed upon them, and the railways of thirty years ago, and their traffic.

Formerly railways were for the most part made as level and as straight as practicable, a large expenditure being incurred for this

[1] The discussion upon this Paper extended over portions of two evenings, but an abstract of the whole is given consecutively.

particular object. The traffic, both in passengers and in goods, was light; and the speed was not great for either. The mineral traffic of some railways was considerable, but the comparative infrequency of trains rendered it possible to work this traffic at a slow speed, and therefore with locomotives of no great power.

Latterly, however, both aspects of the case are changed. In order to cheapen the construction of railways, with the view to introduce them into less populous and less productive districts, engineers have been led to follow the contour of the country more closely, both as to the vertical profile and the general direction of valleys and hills. The consequence has been severe gradients, often concurring with curves of small radius, thus increasing the difficulties of the Locomotive Engineer; and this has especially been the case in coal and mineral districts.

In the colonies, also, the necessity for a smaller expenditure on railways has induced engineers to follow more nearly the surface of the ground; and as high speeds and frequent communication are not necessary, heavy engines have been employed for the purpose of gaining great tractive power, since load rather than speed is the desideratum. A like state of things exists in most parts of the continent of Europe, where heavy and slow trains, both of passengers and goods, are the rule; thus permitting the service to be carried on at a much lower rate per ton per mile than the rapid traffic of Great Britain renders possible.

Passenger Traffic.

The passenger traffic of this kingdom has, of late years, so increased, that even express trains are now worked, for the most part, with coupled engines. Such engines, specially arranged for passenger traffic, first came under the Author's observation in the year 1848. At that date the East Lancashire railway had a heavy traffic and frequent trains on a line with gradients of 1 in 38 and 1 in 40. It therefore became imperative to procure locomotives having additional points of contact with the rails, in order to prevent their slipping, and to afford greater facility for the rapid starting of the trains from the stations, which occur at short intervals. Since that time increase of size has been everywhere found to be a necessity; and while the outside frames of inside cylinder engines have been generally got rid of, the inside cylinder arrangement has been almost universally adopted, notwithstanding the disadvantage presented in it of a cranked driving axle.

Great Northern Railway Express Engine (Plate 1, Fig. 1).

In the first example of a locomotive, however, to which attention is directed, outside cylinders have been resumed; perhaps as a necessary consequence of the adoption of a bogie frame with four wheels instead of a pair of leading wheels, to insure greater freedom in passing round curves at high speeds, for which special object the engine has been designed by the Locomotive Engineer of the Great Northern railway. The weight on each of the four front wheels is at the same time proportionately diminished, and with great advantage. It will be observed that there is one frame only on each side of the fire-box and inside the wheels, and that this frame receives the cylinders. These frames are of one solid plate, $1\frac{1}{4}$ inch thick, connected behind the fire-box by a cast-iron cross frame, elsewhere and by wrought-iron cross brackets and by the buffer beam, receiving the cylinders in front on each side of the smoke-box. This position gives convenient access to the cylinders, the pistons and rods, the connecting rods, the guide bars, and the motion blocks, all of which are placed outside the frames. The slide valves and their gearing are inside the frames, though somewhat nearer to them than in inside cylinder engines. The train is drawn from the cast-iron cross frame, which, together with the longitudinal frames, is so attached as to allow of the free expansion of the boiler, to avoid any strain being put upon the latter by the haulage of the train, and to free it from the contortions formerly occurring when rigidly connected with the frames at several points. The proper adjustment of the driving axle boxes is secured by wedge-shaped horn blocks, attached to the frames by a screw with lock nuts. The boiler is made of Yorkshire plates, $\frac{1}{2}$ inch thick, and is of the lap-jointed class, having double-riveted longitudinal and single-riveted vertical seams. The pressure of steam employed is 140 lbs. to the square inch.

The fire-box is of copper, the tube plate being $\frac{3}{4}$ inch thick, the back plate $\frac{5}{8}$ inch thick, and the sides and crown $\frac{1}{2}$ inch thick. It is of the usual square form, and is attached to the external iron shell by a square iron frame at the bottom; and at the front, sides, and back, by screwed copper bolts, riveted at both ends. The roof is stayed to the external shell by wrought-iron radiating stays, $\frac{7}{8}$ inch in diameter, screwed into the copper plates and into the iron casing. The fire-box contains a sloping midfeather in such a position as to deflect the heated gases from the fire before

they reach the tubes. The air admitted through the fire-door, and directed by the ordinary deflecting plate, is thus thoroughly mixed up with the heated gases, thereby securing the best possible combustion.

The boiler is fed by two injectors, and the water can be supplied without reference to the motion of the engine. The tubes are of brass, two hundred and seventeen in number, and each $1\frac{9}{16}$ inch external diameter. This comparatively small diameter tends to secure the more effectual abstraction of heat from the gases passing through the tubes.

The cylinders are outside the frames; they are 18 inches in diameter and 28 inches stroke; a size, perhaps, never before attempted in this country for passenger engines. The joint of each steam-chest cover is in the centre line of the valve spindle, so that when the cover is removed, ready access to the valve facing is obtained. The valve gearing is of the ordinary shifting link class. The small ends of the connecting rods are furnished with solid bushes of gun-metal, which succeed admirably, the connecting rods having run a distance of more than 50,000 miles without renewal. The driving wheels are 8 feet 1 inch in diameter; and the trailing wheels are 4 feet 1 inch in diameter. The end of the engine is carried upon six volute springs, placed in a trough under the foot-plate, as being more conveniently got in than the ordinary elliptical springs. There is a cab over the foot plate, for the protection of the driver and the fireman.

The front of the engine is carried upon a four-wheeled bogie frame, with a cylindrical centre pin, the hole in the bush being bored taper. It has also sliding bearings in the line of the side frames under the cylinder steam chests, to give greater stability to the engine when running at high speeds. This bogie arrangement imparts flexibility to the engine when passing round curves, and secures the greatest steadiness of the whole machine, at whatever speed it runs.

The mode of attaching the inner to the outer fire-box, by stays screwed into each of the plates without the intervention of iron girder bars, though in use for some time in Belgium, has not been extensively adopted in this country. By this arrangement the large amount of deposit generally existing upon girder boxes is prevented, and the facility for cleansing is much greater. The liability of the tube holes in the copper plate to become oval, by the pressure of the ends of the girders upon the edge of the tube plate, is also got rid of. It is understood that no countervailing disadvantages have arisen from the adoption of the system.

The heating surface in this engine is:

In the tubes	1,043 square feet.
,, fire-box	122 ,,
Total	1,165 square feet.

The fire-grate area is 17·6 square feet.

The weight upon the wheels, when the engine is in working order, is:

On the driving wheels	15 tons.
„ hind wheels	8 ,,
„ bogie	15 ,,

The distance from the centre of the hind wheels to the centre of the bogie pin is 19 feet 5 inches.

The engine is capable of drawing a weight of 356 tons on a level at a speed of 45 miles per hour,[1] with a working pressure of 140 lbs. Its consumption of coal, with trains averaging sixteen carriages of 10 tons weight each, has been 27 lbs. per mile, including getting up steam and piloting. The cost of repairs has been nominal, two engines having run 45,000 miles without missing a single turn. Mr. Stirling, however, gives it as his opinion, that the cost of maintaining and renewing passenger engines on the Great Northern railway is $2\frac{1}{2}d.$ per mile. This engine has been designed to fulfil the requirements of a quick and heavy passenger traffic; and in the whole arrangement of the parts, as well as in the excellence of the materials selected for the construction, both durability and economy of repair have been kept in view.

London and North Western Railway Passenger Engine (Plate 1, Fig. 2).

The next example of an engine for fast passenger traffic is one designed for the London and North Western railway by the late Locomotive Engineer, and modified in some of its details by his successor.

The cylinders are placed inside between the frames, each of which is cut out of a piece of solid plate, 1 inch thick. The

[1] The load drawn includes in all cases the weight of the engine and tender.

frames extend the whole length of the engine, and are connected by the buffer beam, by the cylinders, the motion plate, an angled bracket in front of the fire-box, and by a vertical buffing plate and horizontal cross plates behind the fire-box. The train is drawn from these frames, which are free to allow the boiler to slide upon them at every point behind the smoke-box. The boiler is of Low Moor plates, $\frac{13}{32}$ inch thick, and is lap-jointed. The steam pressure employed is 120 lbs. per square inch, and it is controlled by two of Ramsbottom's safety valves. The fire-box is of copper, of the ordinary form, fixed to the external shell by a square iron frame at the bottom, and by copper screw stays placed 4 inches apart, and riveted over at both ends; the roof being stayed by longitudinal wrought-iron girders, connected to the external shell by vertical sling stays. The fire-box contains a fire-brick arch extending backward about half the length of the box. Under this arch are two circular holes, 7 inches in diameter, covered by doors which can be worked from the foot plate, so that the amount of air admitted is well within the control of the driver. The fire-doors are of the double lever sliding kind, and invariably secure the admission of air in the middle of the firing hole.

The boiler is fed by two Giffard injectors, to the arrangement of which particular attention is directed (Plate 1, Fig. 3). They are placed vertically behind the fire-box, so as to be easily manipulated by the driver. A vertical screw with a wheel handle regulates the admission of the water to the injector, which ascends and passes through a clack box (that can be closed at pleasure) into the boiler, along an internal pipe, carried forward two-thirds of the length of the barrel of the boiler. By this arrangement all external pipes running forward outside the boiler are done away with, and greater simplicity and freedom from accidents are secured.

The boiler tubes are of brass, one hundred and ninety-two in number, and each $1\frac{7}{8}$ inch external diameter. The cylinders are in the smoke-box; they have a diameter of 17 inches and a stroke of 24 inches, the slide valves being placed vertically between them. Each piston is guided by one upper and one lower steel guide bar, after the fashion of an outside cylinder engine. The valve motion is of the ordinary shifting link class, the valve rods being square at the back part, and working in cast-iron guides. The reversing motion is effected by a screw and fly-wheel, to obviate the danger of the lever flying back, as in the ordinary arrangement, and to lessen the effect on the motion of the train when diminishing the admission of steam.

There are four driving wheels, each 6 feet $7\frac{1}{2}$ inches diameter,

coupled together by outside rods. The leading wheels are 3 feet 7½ inches diameter. The connecting rods are forked, so as to gain a greater length in proportion to the length of the stroke. The cross-head step bushes are of wrought iron case-hardened. The coupling rods are furnished with circular step bushes of white metal. All the rods are of steel.

The end of the engine is carried upon six volute steel springs, three on each side, placed below the axle boxes, all of which are of solid brass, those for the coupled wheels working in steel guides. A cab is placed over the foot plate, to shelter the attendants.

The heating surface of this engine is:

In the tubes	1,013 square feet
,, fire-box	89 ,,
Total	1,102 square feet.

The fire-grate area is 15 square feet.

The distribution of weight, when the engine is in working order, is:

	Tons.	cwts.
On the leading axle	9	9
,, driving axle	11	0
,, trailing axle	8	15
Total	29	4

The total wheel base is 15 feet 8 inches.

The engine will draw a weight of 293 tons on a level at a speed of 45 miles per hour, with a working pressure of 120 lbs. Its consumption of coal per mile is 26·3 lbs., with trains averaging ten carriages; and the cost of repairs, over a period of six years and a half, has been ·52*d.* per mile run, the average mileage being 31,202 per annum.

Great Southern and Western Railway of Ireland Goods Engine (Plate 1, Fig. 4).

The first example of a locomotive specially adapted for goods traffic is the six wheeled coupled goods engine made for the Great Southern and Western railway of Ireland, and consequently suited to a gauge of 5 feet 3 inches. It is believed to be one of the most powerful goods engines in use upon an Irish railway.

There are no frames outside the wheels. The two inside frames extend the whole length of the engine, and are of solid plate,

1 inch thick, connected in front by the buffer beam and cylinders, under the boiler barrel by the motion bracket in front of the fire-box, by a strong $\frac{7}{8}$ inch angled plate, and by a heavy cast-iron block fixed firmly between the frames, forming the base for the foot plate. The train is drawn from this cast-iron block, and the boiler is free to expand along the frames. The horn blocks are of cast steel, and extend on both sides of, and over, the top of the openings for the axle boxes. The axle boxes are of cast iron with brass bearings, and they are adjustable by wedge pieces recessed into the horn blocks, so as to take up the wear; these are held up by screws inserted from the back. The boiler is of Yorkshire plates, $\frac{1}{2}$ inch thick as a rule, but $\frac{3}{4}$ inch where the tubes are fixed. The fire-box is of copper, of the ordinary square form, $\frac{1}{2}$ inch thick, swelled to $\frac{3}{4}$ inch where the tubes are fixed, and connected to the outside shell in the ordinary way.

The boiler is fed by two Giffard injectors, placed horizontally on each side of the fire-box. Some boilers now being made have vertical injectors feeding through the back of the fire-box into the front, thus avoiding all outside pipes, as described in the London and North Western railway passenger engine. The tubes are of brass, one hundred and sixty in number, and each 2 inches external diameter. The safety valves are on Ramsbottom's system, to prevent weighting by the driver. A spark arrester of wire, of the inverted truncated form, is placed in the chimney. The cylinders are 17 inches diameter, with a stroke of 24 inches; the slide valves working vertically between them. The valve motion is of the usual form, the link being shifted by a screw motion, so as to insure absolute control by the driver. All the wheels are coupled, and have a diameter of 5 feet $1\frac{1}{4}$ inch. The tires and the axles are of cast steel. The coupling rod ends are furnished with cast-iron bushes, lined with white metal. The small ends of the connecting rods have wrought-iron steps, case-hardened. The sand-boxes are fixed in the smoke-box, to insure the dryness of the sand. A steam break is applied, in order to obtain a greater degree of safety in descending inclines, and to enable the driver to assist in stopping the train. Its application is shown in the sketch in front of the chimney.

The heating surface of this engine is:

In the tubes	846 square feet.
,, fire-box	93 ,,
Total	939 square feet.

The fire-grate area is about 17·5 square feet.

The weight upon the wheels, when the engine is in working order, is:

	Tons.	cwts.	qrs.
On the leading wheels	10	12	1
,, driving wheels	11	6	3
,, trailing wheels	8	15	2
Total.	30	14	2

The total wheel base is 15 feet 6 inches.

The engine will draw a weight of 607 tons on a level at a speed of 25 miles an hour, with a working pressure of 140 lbs. Its average consumption of coal is 35 lbs. per mile with a load of fifty-five wagons. The cost of repairs has been ·63*d.* per mile.

Bombay, Baroda, and Central India Railway Goods Engine (Plate 1, Fig. 5).

This engine has been specially designed for the working of heavy traffic in India, where the gauge, 5 feet 6 inches, has given great facility for the construction of a powerful engine on a reasonable length of wheel base. It will be found that several appliances exist for suiting this engine to the requirements of a colonial railway, and in this respect it differs from ordinary goods engines in this country. The frames consist of a pair of longitudinal plates, $1\frac{1}{8}$ inch thick, placed inside the wheels, connected at various intervals by the buffer beam, the cylinders, the motion plate, a strong cross bracket in front of the fire-box, a similar one behind it, and by strong plates and angle irons at the foot-plate end. The train is drawn by a pin inserted through these plates, and, as the boiler has no positive attachment to the frames behind the smoke-box tube plate, it is free from all strain arising from the haulage of the train.

The boiler is of the ordinary form, 4 feet 4 inches diameter, and 10 feet 9 inches long, of Yorkshire plates, $\frac{1}{2}$ inch thick. The fire-box shell is of the same material and thickness, deep in front, but sloping backwards, with a long inclined fire-grate suitable for burning the small and inferior coal usually procurable in India. The fire-box proper is of copper, of the same tapering form as the external shell, all the plates being $\frac{1}{2}$ inch thick, but the tube plate is swelled to $\frac{7}{8}$ inch where bored to receive the tubes. The wrought-iron roof girders in this engine run transversely, so as to obviate the necessity for their being so deep as would have been requisite had they been placed longitudinally. A spark arrester,

of wire, is fixed on the top of the blast pipe, and extends into the chimney.

The water is supplied to the boiler by two injectors, either of which is capable of delivering the amount of water usually evaporated. The tubes are of brass, two hundred and twenty-two in number, and each 2 inches external diameter. The cylinders are 18 inches diameter, with a stroke of 24 inches; the slide valves being placed vertically between them. The valve motion is of the straight link double lever form patented by Mr. Alexander Allan. All the wheels are coupled, and are 5 feet diameter on the tread. There is a cab with a double roof, of wood and of iron, over the foot plate, to shelter the driver from the rain and the great heat. A cow-catcher is fixed in front of the buffer beam, to fit the engine for use on the unfenced railways of India.

The escape of smoke, when the engine is standing still, is prevented by the application of Mr. D. K. Clark's apparatus, for the introduction of air above the surface of the fire, by means of jets of steam through hollow stay tubes at the front and back of the fire-box.

The heating surface of this engine is:

In the tubes	1,278·0 square feet.
,, fire-box	99·3 ,,
Total.	1,377·3 square feet.

The fire-grate area is about 25·5 square feet.

The engine will draw a weight of 694 tons on a level at a speed of 25 miles per hour, with a working pressure of 140 lbs. Its consumption of coal is 59·25 lbs. per mile for an average load of 490 tons. The cost of repairs has been 2·15 annas, or, say, 3·22*d.* per mile.

A peculiar feature of this engine is the position of the hind axle under the fire-box, permitted by the long sloping fire-grate, and by the shallowness of the end of the fire-box. This arrangement answers the double purpose of allowing a comparatively short wheel base and an equable distribution of the weight of the engine upon the wheels, 11 tons, 11 tons 16 cwt., and 11 tons 16 cwt., being carried on the leading, the driving, and the trailing wheels respectively. As there is less weight on the leading wheels than on either of the other pairs, it might be supposed that there would be danger of the engine running off the line under certain circumstances; but this is not the case, as the weight actually upon the springs of the leading wheels is greater than on those of the driving wheels.

Furness Railway Tank Engine (Plate 1, Fig. 6).

This locomotive was constructed for the conveyance of mineral or heavy goods traffic over a portion of the Furness railways, having gradients of 1 in 100, and 1 in 80, &c., for 11 miles. It was desired to get as powerful an engine as possible on six wheels, with inside cylinders, and to carry fuel and water sufficient for a considerable distance, in case it was found necessary to take the train forward on the main line. The cylinders are between the two frames, which extend the whole length of the engine, and are $1\frac{1}{4}$ inch thick. Besides being connected by the cylinders, the frames are tied by two cross brackets under the boiler, by the buffer plank in front of the cylinders, and by four cross ties behind the fire-box; the frames are further strengthened externally by heavy angle irons arranged for carrying the water tanks. The train is drawn from the foot plate, and as the boiler is free to slide in the frames, all haulage strain is removed from it, as well as that arising from a too unyielding connection with the frames. The horn blocks are of cast iron. Those of the driving and the front axles are carried round the top of the horn plate to strengthen the frames. The boiler is of Yorkshire plates, $\frac{1}{2}$ inch thick as a rule, but $\frac{3}{4}$ inch thick where the tubes are fixed. The fire-box is of copper, $\frac{9}{16}$ inch thick, of the ordinary square form, connected with the outside shell by a square wrought-iron frame at the bottom, and by copper screw stays at the sides, front and back. The roof is stayed by longitudinal wrought-iron girders, connected, by means of sling stays, with T irons riveted to the roof of the external casing. The proper combustion of the fuel is effected by the admission of air through the fire door, deflected on to the surface of the fire by the ordinary scoop, aided by a fire-brick arch, placed across the fire-box under the tubes, which serves also to prevent the emission of sparks through the tubes and chimney. The fire-bars are simple flat pieces of iron, with two corners cut off, and are supported by two cross bars, with pins to keep the distances equal. The boiler is fed by two injectors, and the engine can therefore stand any required time, when waiting as a pilot, without being set in motion to obtain water for the boiler. The tubes are of brass, one hundred and eighty-six in number, and each 2 inches external diameter. The cylinders are 18 inches diameter, with a stroke of 24 inches, and the valves work vertically between them. The valve gearing is of the ordinary shifting link class, and is reversed by the common lever handle. All the wheels are

coupled, and have a diameter of 4 feet 6½ inches. The end of the engine is carried by a transverse elliptical spring. A coal bunker and cab are conveniently placed on the foot plate. The arms of the crank axle, which is of Bessemer steel, are hooped, to prevent accident in case of fracture.

As the engine is intended to work in either direction, the cab is arranged as a screen both forward and backward.

Tanks to contain 1,000 gallons of water are placed along each side of the smoke-box, the boiler, and the fire-box, above the level of the frame. The coal is carried behind the engineman's platform in bunkers, which hold 2 tons. A powerful screw break is attached to the engine, actuating six blocks in front of each of the six wheels. Sand-boxes supply sand in front of, or behind, each wheel, as required, and are so contrived as to be opened or closed by one set of levers for each direction of the engine.

The heating surface in this engine is:

In the tubes	1,047·8 square feet.
,, fire-box	96·2 ,,
Total . . .	1,144·0 square feet.

The fire-grate area is nearly 15 square feet.

The weight upon the wheels, when the engine is in working order and the tanks full, is:

	Tons.	cwt.
On the leading wheels	13	16
,, driving wheels	14	11
,, trailing wheels	13	8
Total	41	15

The total wheel base is 15 feet.

The engine will draw a weight of 872 tons on a level at a speed of 20 miles per hour, and a weight of 367 tons, up an incline of 1 in 80, at a speed of 11¾ miles per hour, with a working pressure of 145 lbs. to the square inch. Its consumption of fuel with this latter load has been 40·16 lbs. per mile, taking the whole trip, which includes the descent as well as the ascent of the gradients before alluded to. The cost of repairs has not been taken into account, as the distance run does not usually exceed 76 miles per day.

This engine was designed to obtain as much power as was possible upon six wheels. The frames have been put inside

the wheels, to allow convenient access to the motive parts; the cylinders being placed inside, to secure great structural stability. The tanks are arranged alongside the boiler, to distribute equal weights upon the wheels, whether the tanks are full or empty. The distribution of the weight, when they are empty, is:

	Tons.	cwts.	qrs.
On the leading wheels	11	7	2
,, driving wheels	11	16	2
,, trailing wheels	10	8	2

It is believed that the engine has in all respects answered the purpose for which it was built.

For engines with rigid frames, a simple and convenient arrangement has recently been applied, in the shape of a sliding top to the leading, and sometimes to the trailing, axle boxes (Plate 1, Fig. 7). This cap has a double incline in the transverse direction of the engine. The axle box has also similar corresponding inclines, so that when passing round a curve the leading wheels are free to move sideways, without at once carrying the engine with them. As the axle box incline must at the same time lift the engine when so sliding, the gravity of the engine tends to make it assume its normal position on the axle boxes as soon as the road permits this to be done. This plan has been largely adopted on the Midland railway, where the side play allowed is 1 inch, and it is found to give very favourable results.

The Fairlie System of Locomotives.

This system has been designed with the object of giving extreme freedom of movement to the engine and wheels, while securing sufficient stability to the boilers and their adjuncts. It has been also sought to utilise the whole weight of the fuel and water for the purpose of tractive adhesion.

On the Tarapaca railways an engine of this class has been worked on severe inclines in competition with the Evans engine, built in the United States. It has four cylinders, each of 15 inches diameter, and with a stroke of 22 inches. The diameter of the twelve driving wheels, running in two bogie frames, is 3 feet 6 inches and the weight of the engine when empty is 44 tons. This engine has taken a load of 120 tons up an incline with a maximum gradient of 1 in 22 and a minimum gradient of 1 in 29 for 24 miles, consuming 30 cwt. of coal for the trip, or 140 lbs. per mile, which is equivalent to 1·17 lb. of coal per ton per mile.

On the Great Luxembourg railway an engine of the same class with four cylinders of 15 inches diameter and 24 inches stroke, the diameter of the twelve driving wheels, running in two bogies, being 3 feet 6 inches, and the total heating surface being 1,688 square feet, has taken a gross load of 400 tons up long inclines of 1 in 62, with a consumption of fuel of 27·10 kilogrammes per kilometre, equal to, say, 95·55 lbs. per mile.

On several railways, from which reports have been received, it has been stated that the cost of repair of these engines has been inconsiderable, while the wear of the tires and of the flanges has been inappreciable.

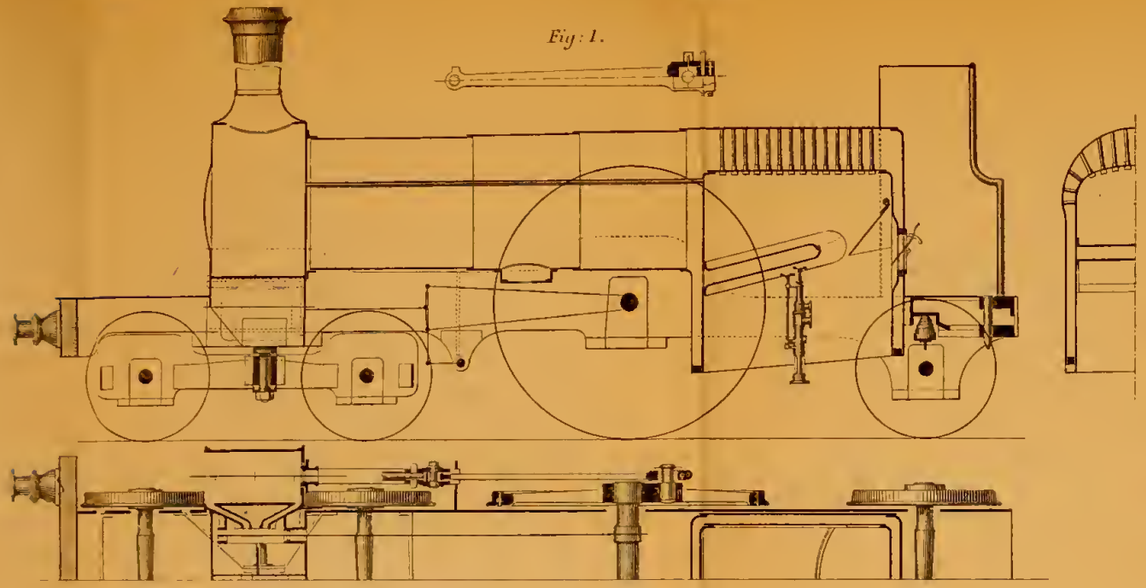
Before concluding, reference must be made to the great advantages which have accrued to the users of locomotive engines, by the adoption of steel instead of iron for many parts, especially for tires and axles, whether the latter are cranked or straight. Tires which, when of iron, worked 55,000 miles, now continue running 135,000 miles, before requiring to be replaced. Cranked axles (one of the most difficult pieces of a locomotive to deal with both in manufacture and in maintenance), when of iron have performed 45,000 or 50,000 miles; whereas, with steel, 170,000 to 200,000 miles are now obtained under similar circumstances; so that in this case, as well as in that of the steel tires, locomotives, which form a considerable part of the capital stock of a railway company, are kept out of the shops, and are in service for a much longer portion of their existence than when iron tires and iron axles were employed. To this advantage must also be added that of reduced friction upon the axle journals, where steel journals and brass bearings are used together in locomotive engines.

There can be little doubt but that the tendency in the manufacture and use of locomotive engines has been to simplify their construction: to secure, by the adoption of more durable, though, perhaps, more expensive, material, a more serviceable machine, and one which, taking into account the continually increasing amount of work imposed upon it, is doing that work with considerably greater economy than in former years.

The Paper is illustrated by a series of drawings and diagrams, from which Plate 1 has been compiled.

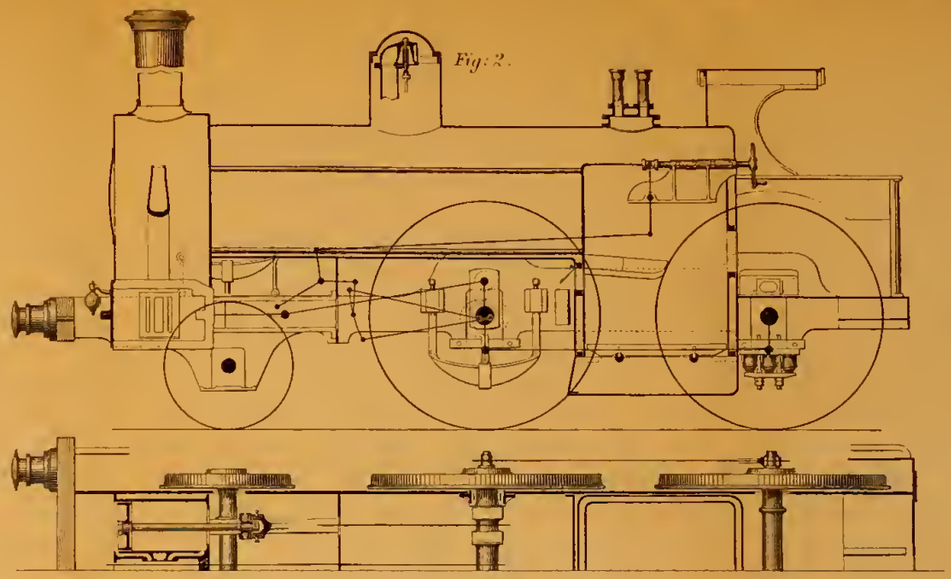
[Mr. Robinson

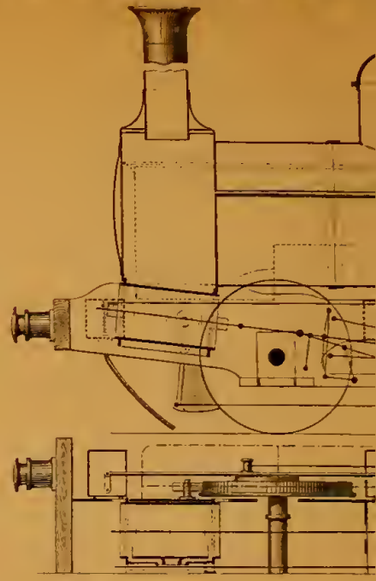
Fig: 1.



GREAT NORTHERN RAILWAY EXPRESS ENGINE.

Fig: 2.



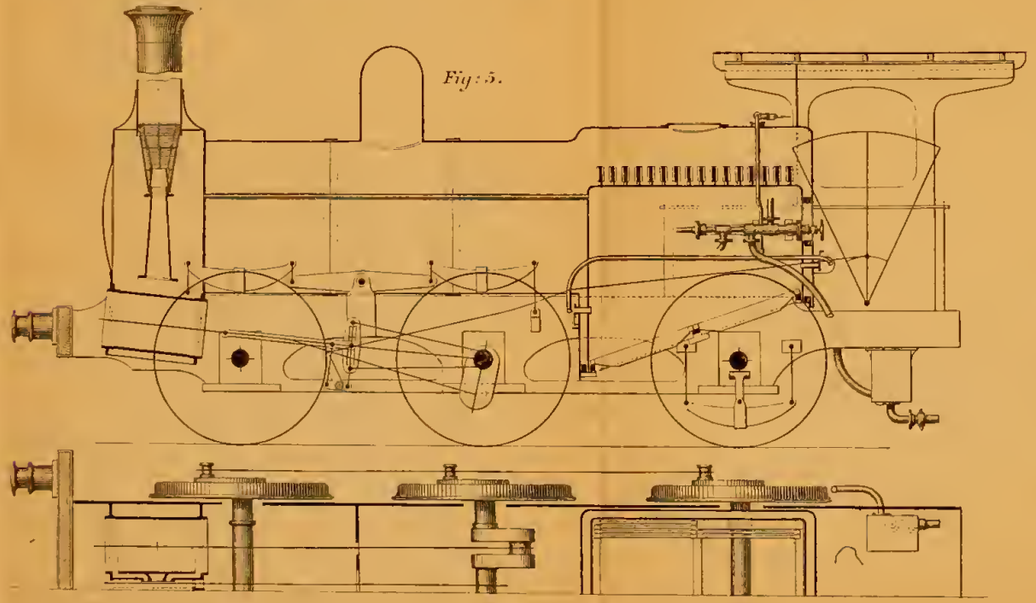


LONDON AND NORTH WESTERN RAILWAY PASSENGER ENGINE.

Scale for Figs. 1, 2, 4, 5 & 6.

0 1 2 3 4 5 6 7 8 9 10 15 20 Feet

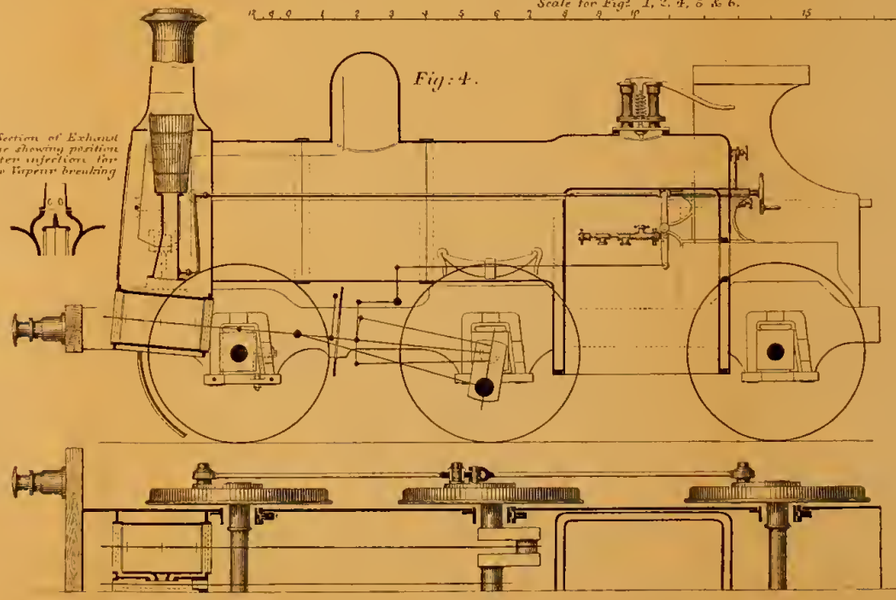
Fig: 3.



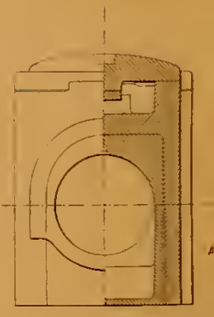
BOMBAY, BARODA AND CENTRAL INDIA RAILWAY GOODS ENGINE.

Fig: 4.

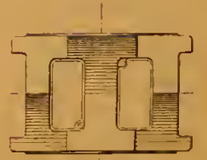
Cross Section of Exhaust Passage showing position of water injectors for Centre Vapour breaking



GREAT SOUTHERN AND WESTERN RAILWAY OF IRELAND GOODS ENGINE.

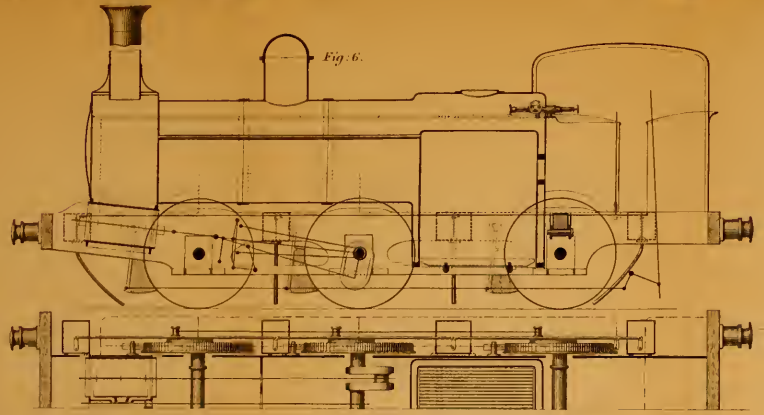


0 3



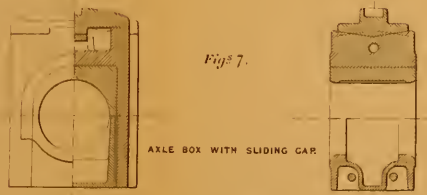
AXLE BOX TOP.

Fig: 6.



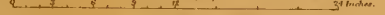
FURNESS RAILWAY TANK ENGINE.

Figs 7.



AXLE BOX WITH SLIDING CAP.

Scale for Figs 7.



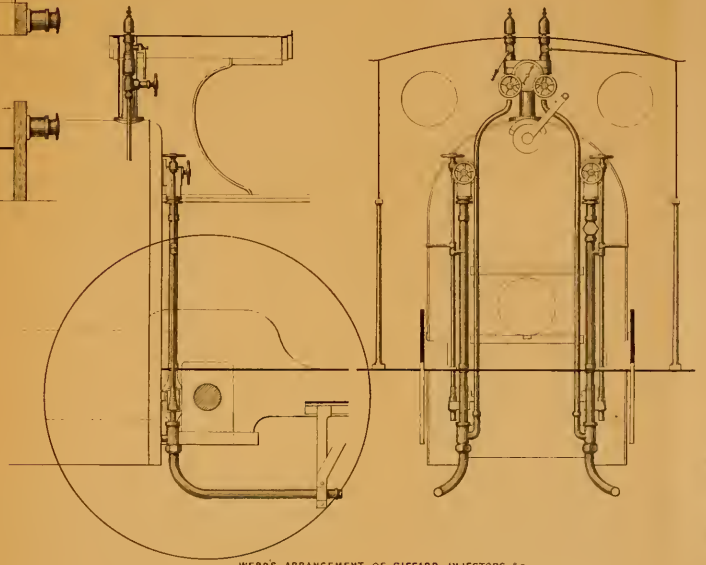
3½ Inches.

AXLE BOX TOP.

SLIDING CAP SEEN FROM UNDERSIDE.

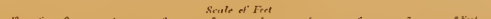
TOP OF SLIDING CAP.

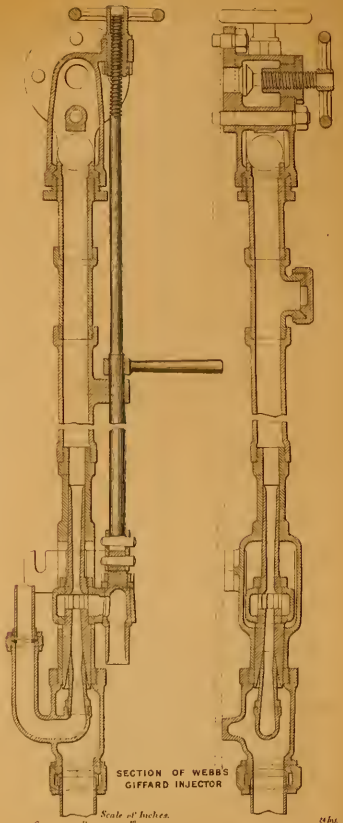
Figs 3.



WEBB'S ARRANGEMENT OF GIFFARD INJECTORS &c.

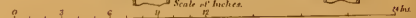
Scale of Feet





SECTION OF WEBB'S GIFFARD INJECTOR

Scale of Inches.



THOS KELL LITH 40 KING ST COVENT GARDEN.

Mr. Robinson remarked that the Paper contained a record of facts rather than of opinions. In consequence of some remarks about the object of the communication, he might state that he did not see how, on the one hand, a history of the locomotive could be written, or, on the other hand, a description of a hypothetical and perfect engine, as to design and material, could be given, when the Institution had prescribed Subjects for Papers, and, for the one taken up required that it should have reference to "duty performed" and to "cost of repairs," so that the engine must have run, for a longer or a shorter period, upon a railway. An outsider might naturally remark upon the diversity of the means employed by different engineers to accomplish the same objects. The traffic, for instance, of the London and North Western, the Midland, and the Great Northern railway companies was very similar as regards quantity and speed of conveyance, and the gradients of those lines were not very dissimilar, but the engines employed differed materially in their details. Locomotive engine makers sometimes wondered how engineers could contrive so many varieties. The only matter of certainty was that every engine must have a boiler, cylinders, and wheels: the rest was much a matter of choice with the locomotive superintendent. It was perhaps repeating the same condition of things in these days, in regard to mechanical science, as existed in former days in regard to arts and literature; "*Quot homines, tot sententiæ:*" as many engineers, so many engines.

Mr. Edward Reynolds regretted that the Paper should have been confined to bare facts, emanating as it did from an Author so well qualified to enunciate the principles upon which successful practice had been founded. The principal thing that occurred to him was the constant simplification in the construction of engines, for which locomotive engineers deserved credit. The higher the class of engine the more free it was from fancy work. This was most conspicuous in the Great Northern and the London and North Western express engines, which were remarkable in several respects as types of a class. On the Continent, and still in many parts of England, constant efforts were being made to enlarge the size of boilers, and so to give apparently more power to the engines. These, however, were smaller than those formerly used on the same railways to do much less work. This was peculiarly striking on the Great Northern railway, where smaller boilers had been substituted in a large number of existing engines, he believed with exceedingly satisfactory results both as to power and economical efficiency; the improvement being in some degree due to the care exercised in so moderating the flue area, that there should

be proper friction of the products of combustion against the heating surface. The large power developed by locomotive engines had often been noticed. Take as an example the Great Northern express engines described in the Paper. The trains drawn by them averaged about sixteen carriages, and ran at an average speed of 50 miles an hour. The trains weighed 160 tons, the engine 38 tons, and the tender 27 tons—in all 225 tons. According to existing data as to resistances in traction on a level (and all railways were of an average level), the resistance at 50 miles an hour could not be less than 22·6 lbs. per ton, and this would amount to a total tractive force of 5,085 lbs., equal to an average pressure of 53½ lbs. in the cylinders. This speed and resistance gave the extraordinary result of 678 H.P. He believed that 27 lbs. a mile was the record of two or three years' working of six of these engines. At a speed of 50 miles an hour this would amount to 1,350 lbs. per hour, which was less than 2 lbs. a mile per H.P. per hour for actual realised power, not indicated power from which deductions had to be made for friction, &c. This striking result, he believed, had not been surpassed in the engines of any ocean steam ships, with all their appliances; he did not allude to experimental trips, but to actual working. In the interest of science, he thought it was desirable that some experiments should be instituted, to ascertain precisely the duty in reference to the consumption of fuel of those engines. Again, it was noticeable that the 678 H.P. was obtained from only 1,165 feet of total heating surface, or 1·7 foot per H.P. The Paper stated that the link motion was of the ordinary shifting kind. Now the link motion, though a certain amount of merit was sometimes conceded to it, as an elegant and trustworthy contrivance, was not, he thought, sufficiently appreciated by engineers. All kinds of schemes were devised for superseding it; and the feeling on the subject was so strong that it was worth while to combat it. In the lucid and instructive tables published by the Judges of the Royal Agricultural Society, especially those with reference to the Cardiff show,[1] the duty of the engine as a whole including the boiler, &c., had been carefully separated from that done by the engine proper; and the engine doing the most duty per lb. of water was one with merely a slide valve worked by a motion analogous to the link motion, and without a separate expansion valve. In spite of that, there was a locomotive engine in the Vienna Exhibition of 1873 with separate expansion valves; and only last week a manufacturer

[1] *Vide* "Journal of the Royal Agricultural Society," 2nd series, Vol. VIII., p. 404, *et seq.*

consulted him as to what sort of separate expansion valve should be used, as there was no demand for engines without them. He would suggest whether this economy was not obtained by what was considered a defect in the link motion. The probability was that the Great Northern engines, when running with express trains, cut off the steam at from 3 inches to 4 inches of the stroke, expanding it from that point until 18 inches or 20 inches of the stroke; then exhausting the steam at one end and commencing compression at the other. Reference to any locomotive-engine diagram would show, that the compression never rose anywhere near the point that might be expected. The pressure that was not found in compression might be consumed in giving heat to the cylinder, and in putting it in a condition to do good duty with the steam that came into it. That might account for the high duty got by the link motion. There was another point on which he desired information. Notwithstanding the successful experiments made in heating feed-water, showing an economy of from 10 per cent. to 12 per cent., the engineers of the leading railways had continued the use of simple injectors. An injector might be a perfect machine in its way, because any loss of power by undue friction would go to heat the water, so that there was no direct loss of power; still it could hardly be imagined why 10 per cent. economy in fuel should be sacrificed.

Mr. F. W. Webb said he did not take to himself the credit of designing the London and North Western express engine, though there were certain portions of it he had endeavoured to simplify, and to some extent successfully. He was still trying further experiments, and he believed Mr. Bouch, of the North Eastern railway, had also tried some independent experiments, but in a different form, with regard to what might be called a cumulative blast-pipe. By the method he had adopted, and which had been at work for more than two years, the same amount of work was done with a considerable reduction in the fuel; and in a large measure the drawing of ashes from the fire-box to the smoke-box was prevented. With regard to heating the feed-water, during the time he was with Mr. Ramsbottom on the London and North Western line every feasible method was tried in the "Sharp" class of engine, but no economy worth the complications was obtained. If a portion of the exhaust steam for heating the feed-water were discharged, the blast-pipe had to be contracted to get the necessary amount of steam to work the engine. When the 7 feet 6 inches express engines, known as the "Lady of the Lake" class, were first built, ten were made with pumps and the

remainder with injectors. He had examined the performance of the engines for ten years, and the result was, if anything, in favour of the injectors. With regard to the injectors now in use on the London and North Western railway, of course there was nothing new in principle, but he had simplified them, and they were so arranged that all external feed-pipes between the injector and the boiler were done away with. The injector supplied the boiler through an internal pipe, which, for convenience, was of the same length as the boiler tubes; indeed one of the boiler tubes was used for the purpose, fitted into the back plate of the fire-box casing, and over it was placed the clack box. When the water arrived at the end of the pipe and was distributed it was nearly at the boiling point. With engines so fitted, there had been very little trouble with leaky tubes; and he believed it would be found in me that the grooving of the boiler plates, due to expansion and contraction, would be reduced. An objection was at first raised, that when the water was bad the pipes would be furred; but one engine had been working for two years without any deposit in the pipe, and this with very indifferent water; and even if they did fur they could be cleaned from time to time without removing the pipe or clack box. The system had also this advantage: that by uncoupling the tender the water could be drained off from engines standing in the open air without any risk of their bursting in frosty weather. He had five hundred now working. Air holes in the fire-box had been abandoned, as they caused much increase in the wear and tear of the fire-box plates. As to the material of the boilers, he was now using steel entirely, and there were at work two hundred of the kind shown in the International Exhibition this year, but with copper boxes. He had picked up that morning in the workshop some pieces which would show the kind of test applied to the steel plates. The tensile strength of the piece he exhibited was from 32 to 34 tons per square inch, and it would stretch 25 per cent. before breaking. The percentage of carbon contained in it varied from 0·2 to 0·22 or 0·23. He had been making experiments as to the best material for fire-boxes. Having heard a good deal about the Pittsburg steel, he went when in America to Pittsburg, and certainly saw there results which he had not witnessed in this country; but now he was able to obtain them. The fire-box plate of the engine in the Exhibition was brought out of the rollers, and thrown into a tank of cold water, the tank being 16 feet long and 6 feet deep; the plate was then put into the annealing furnace, and returned again to the water, and this process was repeated four times. A piece of that steel would

bend double when cold without annealing after the last dipping. He believed it had a great deal to do with the ultimate ductility of the steel; and it proved that the steel was thoroughly reliable for fire-boxes, since it would stand that sudden alteration of temperature. He was now putting in a large number of steel tubes. To show what could be done, he had rolled down the old steel tires and made them into tubes, and the result so far had been very good. With regard to the Le Chatelier breaks, they had been abandoned altogether, as they were found to cut the cylinders, although provided with water injection. Mr. Ramsbottom put them on twenty of the engines working in the South Wales District, but the result was unsatisfactory, and they had not been used since. He had lately made some experiments on the Metropolitan District line. He had long thought that the engines on that line were far too heavy for their work. One of the trains was now being run with an engine twenty years old, the only difference being that the blast-pipe had been altered and condenser-pipes put on. It carried 700 gallons of water, which was found sufficient to take the train from the Mansion House Station round by Willesden to Broad Street, making the usual number of stoppages. The engine weighed 27 tons, and it was doing the same work as other engines weighing 47 tons. It had 16-inch cylinders, with a length of stroke of 20 inches, and a working pressure of 120 lbs. per square inch; the weight of the train being about 52 tons, exclusive of the engine. That showed the necessity for inquiry as to what was necessary for the Metropolitan work. Considerably less water was used than with the other engines, and the temperature of the water in the tank, on arriving at the Mansion House, was lower than in the others. If the engine now under trial proved sufficiently large for the work, a saving might be effected of more than a million and a half tons per annum of useless weight at present running over the road. The engine would start the train as quickly as the others, but to his mind not quickly enough. What was wanted for that purpose was a smaller wheel, 4 feet or 4 feet 6 inches in diameter. The running outside the tunnel was quicker than inside. On the Metropolitan District railway he had employed a water-break, borrowing a cylinder full of water from the boiler to put on the break, and replacing it in the boiler when in the act of taking off the break; this he did by using a cylinder full of steam, so that there was but little loss. It was not used at present as a continuous break, but only to the engine wheels. The continuous break was not yet applied to the long express trains on the

London and North Western railway. A recent experiment on the Trent Valley line showed that a train of six carriages, travelling at the rate of 40 miles an hour, could be pulled up in eighteen seconds. The thickness of the steel plate in the boilers was exactly the same as that of the iron plate, as he preferred a longer life for the boiler with a better material, instead of reducing the thickness in proportion to the greater strength. The longitudinal seams were punched $\frac{5}{8}$ inch, and the transverse seams $\frac{3}{4}$ inch, and then annealed. After the boiler was plated together, a welt was put on inside and outside the longitudinal seam, and the three thicknesses were rimered through, so that there was the same strain on all the rivets. The size of the wheels was being somewhat reduced, to insure a greater uniformity of speed both up hill and down hill. The only employment of a strip of copper in the steel boilers was in putting in the tube plate of the fire-box.

Mr. Price Williams would have been glad if, in addition to the description of the distinguishing characteristics of the most recent and improved types of locomotive engines, the Author had furnished the particulars of the economical results that had followed the simplification in construction, and the employment of the more durable material, steel, to which only brief allusion had been made. He had recently visited the Crewe works, and could bear testimony to the great advance in improving and simplifying the construction of the locomotive, which was, it appeared, largely due to the more general use of steel in its manufacture. The increased efficiency and economy resulting from the substitution of steel for iron in the wearing parts of the engine must, in his opinion, be very appreciable. He thought the members generally would like to have from Mr. Webb detailed information showing the economical results of the recent improvements in locomotive construction. Personally he should feel much indebted for these particulars, as it would materially assist him in determining the average life policies of rolling stock. It was important to learn the reason of the great difference observable in the construction of the Great Northern and of the London and North Western express engines, both having been designed, he believed, for railways similarly circumstanced as regarded gradients and the nature of the traffic, and both being intended to meet the requirements of the largely increased loads, due to the conveyance of third-class passengers by express trains. It appeared to him that the large driving wheel of the Great Northern engine, with its bogie wheel arrangement, was not so well calculated to effect the desired object as the arrangement

shown in the London and North Western engine, where the driving wheels were smaller and coupled.

Mr. Fowler, Past-President, said, as he was responsible for the design of the engines on the Metropolitan District railway, which he had pronounced to be too powerful and too heavy for their work, he wished to make a few remarks on the subject. Mr. Webb stated that the trains of the London and North Western Railway Company running between Gloucester Road and the Mansion House weighed 52 tons, and were worked satisfactorily and punctually with engines of 27 tons' weight. It was not necessary to make experiments in proof of such a statement; but it must be remembered that the weight of the trains of the Metropolitan District railway running from the Mansion House to Moorgate Street was 94 tons, that the engines had gradients to surmount of 1 in 70, instead of short gradients of 1 in 100, and that there was a much longer distance of close tunnel during which they must condense their steam. Besides which, the engines of the Metropolitan District and Metropolitan railways must be able to take trains of 113 tons' weight between Moorgate Street and Hammersmith, consisting of six long carriages, and conveying, when full, four hundred and thirty passengers. The engines of the Metropolitan District railway weighed 42 tons 3 cwt., and not 47 tons as stated. The Metropolitan District railway was at present incomplete; when the works now going on were finished, the engines would have trains of 113 tons to deal with, and they must be able to perform the journey with punctuality at all times—when the rails were greasy on foggy days, for instance, and under other adverse circumstances. He maintained that the engines were not too powerful or too heavy on the driving-wheels for their work. If they had to be designed afresh they could not be made of less adhesive weight or power, though no doubt there might be some variation in detail. The trains of the North London railway, running much the same course as the London and North Western trains, weighed more than 100 tons; and he thought it probable that the weight of the London and North Western trains, which was now 52 tons, would eventually reach 120 tons. If so, the 27-ton engines spoken of would be inadequate to their work. At present the small trains of the London and North Western Railway Company running upon the Metropolitan District line occasioned great public inconvenience, being often filled with London and North Western passengers, and having no room for the local traffic from station to station. The number of seats in the trains of the latter Company was

about two hundred, while the Metropolitan trains would accommodate three hundred and thirty or three hundred and sixty passengers. The Hammersmith trains, which probably would, in a few years, be adopted throughout the system, carried four hundred and thirty passengers.

Mr. Webb said, his remark was to the effect that the engines were too heavy, not that they were too powerful. A weight of 12 tons upon the bogie did not help to propel the train. He could build an engine weighing only 32 tons that would be just as powerful as the Metropolitan engines. At present but 30 tons of the weight of the Metropolitan engine served for adhesion; whereas he would employ the whole of the weight of the engine for that purpose. With a six-wheeled coupled engine, smaller wheels, 10 tons' pressure upon each pair of wheels, and a cylinder powerful in proportion, the weight could be reduced without diminishing the power of the engine.

Mr. Fowler thought that a worse-contrived engine for Metropolitan work than a six-wheeled coupled engine could hardly be conceived. It would never do to have a rigid engine with six wheels coupled to pass round curves of 10 chains or 7½ chains radius. It was difficult enough to keep the engines on the line even with the assistance of bogies. The Midland Railway Company, after fully considering the matter, had designed engines for their Metropolitan service weighing 43 tons 10 cwt.—1 ton 7 cwt. heavier than the Metropolitan District engines—and the driving wheels were 6 feet 2 inches in diameter instead of 5 feet 9 inches. The North London engines were of nearly the same weight as the Midland—43 tons 12 cwt.—the driving wheels being 3 inches less in diameter than those of the Metropolitan District. The Great Western engines weighed 33 tons, but they only carried a small tank. He believed that no locomotive engineers had ventured on such a desperate step to increase the adhesion as to couple six wheels of the engine for a line with sharp curves. Mr. Fowler ventured to commend to serious attention the engine of the Great Northern railway, as described in the Paper, in which Mr. Stirling had shown an appreciation of altered conditions. When locomotive engineers had to design engines to run upon iron rails, the maximum weight was wisely limited to 12 tons on a pair of wheels; but when the trains became so heavy, and the required speed so great, that such a weight was inadequate, it was necessary to couple four wheels to give adhesion. The introduction of steel rails had altered this condition of things. Sir John Hawk-

shaw had well suggested that engineers should not make the mistake of lessening the section of the steel rails, but that they should get the full benefit of the additional strength of the better material. Mr. Stirling, with great judgment, had taken advantage of this altered condition, and had put 15 tons on the single driving wheels of the Great Northern engines, and the result was that they performed the service with trains as heavy and as fast as those of the London and North Western railway with a single pair of driving wheels, and in a manner at least equal to the engines of any other line. The gradients on the Great Northern line, it must be remembered, were steeper than those on the London and North Western railway, and yet it had not been found necessary to couple the wheels.

Mr. Bramwell was surprised to hear that the contre-vapeur system of stopping trains had been discontinued in England. Since the last meeting he had written to M. Tresca, of the Conservatoire des Arts et Métiers, for information respecting the use of the contre-vapeur breaks in France, and the reply was as follows:—

"As soon as I received your letter I hastened to inquire into the grounds of the statement you communicated to me, and I give you below an extract from the answer which I have received from the same engineer who showed us, when we visited the Lyons railway, the application of the contre-vapeur system:—'We have not suppressed the contre-vapeur in any of our engines, but on the contrary we are constantly extending its application, and we find it a marvellous success, especially in those sections where we have heavy gradients. We do not find any scoring, neither in the cylinders nor elsewhere.' I may add that for some time past I have occupied myself, both scientifically and also as a question of priority of invention, on all points connected with the contre-vapeur. It is now shown to me that the most sure means of success consist in the injection of water only, even in preference to a mixture of water and steam. When this, coming from the boiler, reaches the waste pipe, it evaporates rapidly, drives out the air by its expansion, and does not permit of the contact of air with the admission orifice. By making use of the contre-vapeur in this manner the injector is not troubled in its working, as it would be, and as it has been, in other instances, owing to the presence of air in the steam in the boiler. It was with a perfect knowledge of the facts that I contributed at the Vienna Exhibition to the obtaining a diploma of honour for M. Le Chatelier, the true inventor of the contre-vapeur, whose loss we are at this moment deploring in Paris.

I shall be glad indeed if you will, on the occasion of the discussion on Tuesday, pay the just tribute of gratitude that is due to him, not only for that which is past, but for that which is to come in the working of railways. If you have need of any other information, I have no doubt I can readily give it to you, and I now confine myself to assuring you that our railways are unanimous in recognising the advantages of the contre-vapeur."

Why the cylinder should score, if the man on the foot plate would only use proper precautions, he could not imagine. Scoring arose from the generation of heat in the cylinder, partly due to the drawing-in of hot air from the smoke-box, but principally from the conversion of power into heat in the cylinder; and this excessive heat, if not got rid of, would accumulate so as to burn the packing and score the cylinder. The getting rid of this heat was the very object of M. Le Chatelier's invention; and it was effected by introducing into the cylinder, prior to reversal, either water alone, issuing from the boiler, or water and steam. A translation of M. Le Chatelier's book, by Mr. Lewis Gordon, was published in 1869,[1] and in the same year a Paper was read on the subject by Mr. Siemens.[2] At that time it was stated that there were in France two thousand engines with this contrivance—fourteen hundred being on the Lyons railway alone. M. Tresca's letter showed that the Lyons Railway Company had never removed the contre-vapeur from any engine to which it had been applied; and thus it must be taken that there were now hundreds of engines on the Lyons railway successfully using the contre-vapeur, while it was stated that the system was about to be discarded from the few engines on which the London and North Western Company had tried it. This was another proof that what answered on the Continent could not be got into use here under a quarter of a century. It required more than thirty years before the bulk of British ironmasters adopted the foreign invention of utilising the waste gases of blast furnaces; and as regarded Scotland, he believed that, even to the present day, those gases were wasted. After the reading of Mr. Siemens' Paper the contre-vapeur was tried on one of the London and South Western railway engines. The experiments were continued through two days, and very interesting results were obtained; other engagements compelled Mr. Bramwell to break off the trials, and he had never had

[1] Railway Economy. Use of Counter-pressure Steam in the Locomotive Engine as a Brake. 8vo. Edinb., 1869.

[2] *Vide* Inst. of Mechanical Engineers. Proceedings, 1870, p. 21.

an opportunity of renewing them. He would briefly state the nature of the experiment and of the results which were, in his judgment, quite satisfactory. The gross weight of the train was 160 tons. The experiments were tried on a part of the line that was straight and level; the rails were dry, and there was but a slight wind. A speed of 40 miles per hour having been reached and maintained, the steam was shut off at a given point, and the train was suffered to come to rest by itself, which it did in 1792 yards. The train was put back, and having again been got to the 40 miles' speed, the steam was shut off and the breaks were applied, when it was brought to rest in 360 yards. The experiment was repeated, but without the breaks and with the contre-vapeur, when it was brought to rest in a length of 904 yards. Break-power was applied to wheels loaded with $36\frac{1}{2}$ tons in all. From indicator diagrams it was ascertained that one of the elements to arrest the train, when neither the contre-vapeur nor the breaks were used, was the pressure of the atmosphere on the pistons, due to the partially vacuous conditions of the cylinders when running in head gear with the regulator shut; this amounted to as much as $\frac{1}{4}$ ton of train resistance. The distance in which the train came to a stop (1792 yards) showed that the total average train resistance was 1·6 ton; deducting the resistance due to piston pressure, the remainder would represent the mean resistance of a train of 160 tons while coming to rest from a speed of 40 miles per hour, and that mean resistance would be found to amount to 19 lbs. per ton. He had prepared an apparatus to be applied to the engine to show accurately the rate of decrease in speed; so that the actual resistance for every velocity, from the maximum to a state of rest, might be ascertained; but he had not yet had time to experiment with it. With the breaks applied the mean resistance was 7·97 tons, from which, if the 1·6 ton of train resistance previously ascertained were deducted, there would remain 6·37 tons as the break resistance, which gave $\frac{1}{6}$ of the insistent weight as the co-efficient of friction between the tires and the rails. With the contre-vapeur the mean resistance obtained was 3·17 tons, equal, after allowing for the net train resistance, to an average of 50 lbs. per square inch back pressure on the pistons. The effect of the contre-vapeur in stopping the train was then tried; and it was found that by its aid the train could be brought to rest in rather less than the distance usually devoted to that purpose. A curious fact was noticed in the indicator diagram taken while the contre-vapeur was in action, namely, that the pressure in the cylinder was as much as 150 lbs., while the boiler-

pressure was only 120 lbs. His first idea, on observing this discrepancy in pressure, was that the indicator was out of order; but on being tested it was found to be perfectly correct. He then came to the conclusion that the excess of pressure arose from suddenly arresting the momentum of the column of steam in the long internal pipe when the steam was rushing with great velocity through that pipe to fill the cavity of the empty cylinder; and that this checking of the velocity gave rise to an increase of pressure, just as in water rams high-pressure was caused by arresting the velocity of a column of water set in motion by a low pressure. In fact, a steam-ram action was set up. He believed not only in the practical feasibility of the Le Chatelier contre-vapeur break but in its high utility, and he desired most sincerely to express, as M. Tresca had suggested, his appreciation of M. Le Chatelier's admirable invention, an invention which had been worked out with great pains by that distinguished engineer and man of science.

He would now pass to another point in the construction of locomotives, and that was the slide valve. He wished to ask locomotive engineers how it was they had not adopted the ordinary double-ported slide, such as was applied with so much advantage to almost every marine engine. The areas subjected to pressure in the double-ported slide and the common slide were respectively 12 and 10, and the stroke of the double-ported slide being only one half that of the single slide, it followed that the power to work it would be only $\frac{6}{10}$ of that required to work the single slide, while the conveniences from the diminished size of the eccentric sheaves, and from the better angles that could be obtained in the links and eccentric rods, would be very great.

He should also be glad to know if the particular arrangement of the fire-box, shown in the Great Northern engine, had been worked long enough to ascertain whether it was open to the old objection of the giving way in boxes with such roof support of the top rows of screwed stays. In this fire-box girder stays were done away with, and the internal fire-box was hung up to the roof of the external fire-box; a practice which Mr. Robinson said was common in Belgium. Mr. Bramwell's observation of Belgian engines was that, although the girder roof stays to the top of the internal fire-box were done away with, as in the Great Northern engine, they were not replaced by a set of ties somewhat inclined, as shown in the drawing of that engine, but the upper part of the external fire-box was made

rectangular, and thus the tie-bolts provided to attach the roofs of the internal and external boxes together were perfectly vertical, while horizontal tie-bars were extended from side to side of the upper part of the external fire-box, to take the lateral pressure. He believed some such plan as this, of cross-ties from side to side of the outer fire-box, was a necessity in cases where the top of the inner box was held up by ties attached to the top of the outer box. He had always understood that when, in former times, in order to relieve the pressure upon the roof girders, two or three stays were put from them to the top, it was found that that top, being held down by these stays, and thereby rendered incapable of being pressed upwards by the steam, did not counteract the lateral pressure upon the sides of the external box; and thus that pressure came upon the top row of screwed stays uniting the inner box to the outer, and under this pressure they gave way. By the Belgian plan, with the rectangular outer box, all the strains were contained by the tie-bolts in the two directions.

Mr. SIEMENS said he was one of the members of the jury in Vienna, where the subject of the contre-vapeur was discussed, and the exceptional reward of a Diploma of Honour was awarded to M. Le Chatelier for that remarkable invention, which was fully appreciated throughout the Continent. It was a contrivance that should always be used; otherwise the result would be a failure. He imagined that on the London and North Western line it had not been adopted as a system, but had been put into the hands of the engine driver to be employed occasionally; sometimes it might have been used properly, whereas at other times probably the water was not put on when reversing. In M. Le Chatelier not only France but Europe had lost one of her ablest engineers. He was a man of very extensive information, of a genial nature, and a true-hearted friend; and he had never known any one more ready to investigate and to appreciate any new idea. M. Le Chatelier had suggested several important improvements in steam economy. He was the first to draw attention to the great advantages of perfect balancing and also of perfect jacketing in using steam expansively. He had, with his friend M. Deville, devised a practical process for the production of aluminium, and had made many valuable suggestions in regard to metallurgical processes. The earnest activity of his mind was such that he could give attention to these matters, and to the high education of his children, while holding the responsible appointments of engineer-in-chief to many large undertakings.

Mr. Crampton said there were certain principles on which all engines, however varying in their details, should be constructed. One point to which his attention had been directed at an early period, 1849, was the question of staying the fire-box; and if there was any merit in the use of the vertical stays in the way described he believed he was entitled to some portion of it. He had also considered the question of balancing. He had discussed it in the "Railway Times," in 1842, when the question arose as to the relative merits of inside and outside cylinders. He then showed that the oscillation had nothing to do with the steam, but was caused by the unbalanced parts, such as the piston-rod, connecting-rod, &c. In the first engines he ever made, in 1847, balances were put on in proportion to the weight of the reciprocating parts; and the first engines made in France in 1848, which were running to the present day, had balances calculated upon the same principle. Although M. Le Chatelier had since worked the matter out more scientifically and accurately, he claimed to have been the first to introduce the principle in locomotives. Several points ought not to be lost sight of. One was to have the machinery under complete control. With this view he had endeavoured, in his early designs, to lower the centre of gravity as much as possible, to have no overhanging weights, to have the maximum weight at the ends and not in the centre, to place the centre of the mass as near as possible to the centre of the line of buffers, to suspend the engine on three points, and where large powers were required to couple two engines back to back. He did not think, however, that if these principles were carried out badly they would work well. These views had been mainly adopted in the engines travelling from Calais to Marseilles. At an early period also, in 1847, he put bearings on the wheels 11 inches long, perceiving that 5-inch or 6-inch bearings were not proportionate to the work to be done; and the whole of the gear was outside the crank pins, with large bearing surface on all the gear. He did not know that there had been any subsequent improvement in these matters. He believed if the engines of the Northern railway of France were in the hands of a man who would go on improving the details, they would last longer and be in the repairing shops less than engines of any other description. Twelve of those engines, in the ten years from 1848 to 1858, ran on an average 27,000 miles a year at a speed of 36 miles an hour. He believed as much work was formerly done with the same pressure of steam as was done now. In 1847, the late Mr. Humphrys and himself made experiments with condensing engines with jackets at the

sides and top and bottom, and they only used 18 lbs. of water per horse power. He was not aware that anything better was obtained at the present time, with equally good commercial results. Many engineers increased the pressure. His impression was that, in the case of marine condensing engines a pressure of steam of 40 lbs., with 5 or 6 times expansion, was the profitable limit. He had made experiments in pumping water to a great height, in which a pressure of 70 lbs. of steam was used, expanding from 10 to 12 times; but the quantity of water lifted was only the same as when the expansion was lowered to 6 times. The indicator diagram showed the theoretical power due to the 12 times expansion, but this was all absorbed in the increased friction of the engine and other losses arising from increased pressure and temperature. These losses were too often overlooked, and unless it could be well established, by long experience, that excessive pressures were in every respect commercially advantageous, no useful purpose would be obtained, but the reverse. In locomotives, the pressure should not exceed 120 lbs. or 130 lbs. with 4 or 5 times expansion.

Mr. Stroudley said, about two years ago he designed, and at the end of last year put to work on the line from Victoria to London Bridge, six locomotives, each of which weighed 24 tons, and had since run 38,000 miles. The average weight of the trains was 59 tons, the number of passengers' seats was three hundred and fifty-four, the average number of miles travelled a day was 150, and the number of stoppages at stations was 179. Three of the engines had been in the shop and had had their wheels turned, and there was a reduction of $\frac{3}{16}$-inch in the thickness of the tires. The coal consumed per mile was 21·63 lbs. The average speed, including stoppages, somewhat exceeded 15 miles an hour. The engines were fitted with six wheels, each 4 feet in diameter, on a wheel-base of 12 feet. The six wheels were coupled, their outside cranks having comparatively short centres. In the previous year, the consumption of coal on the same line, when worked with larger engines and an average load of 7·2 carriages only, was 30 lbs. per mile. A saving had thus been effected in ten months of 1,163 tons of coal, of the value of about £1,450. The curves on the lines were moderately sharp, the sharpest having a radius of 7½ chains. The gradients were 1 in 64, and 1 in 87. The cylinders of the engines were 13 inches in diameter, with a length of stroke of the piston of 20 inches, and the pressure of the steam was 140 lbs. The heating surface of the engine was somewhat over 500 square feet. The engines had worked

continuously, and had given little trouble in the way of repairs. These figures, he thought, supported Mr. Webb's assertion as to the propriety of using lighter engines.

Mr. Webb said he was glad to receive this confirmation of his views. He believed the curves on the suburban district of the Brighton line were not very different from those of the Metropolitan and the Metropolitan District lines. About a month ago he went over the Semmering incline, where there were six or eight-wheeled coupled engines running round curves he believed of about 3-chains radius. He was told while there, that the use of the Le Chatelier break had been attended with the same difficulties as he had experienced in this country. At the Vienna Exhibition a boiler was exhibited, which had been stayed in the same way as the Great Northern express engine. It had been at work about three years, and was cut in two to show the condition of the inside, when some of the stays on the side of the box were observed to be broken. The difficulty as to the expansion of the inner box, while getting up steam, might be avoided, by making the stays in two pieces, linked in the middle with an open eye. On the Semmering incline, the fire-boxes did not last above four years. The one at the Vienna Exhibition was about $\frac{3}{4}$ inch thick. The great difference in temperature, between the inside and the outside, would account for the short life. He believed thick plates were unsuitable for fire-boxes. The Scotch express on the London and North Western railway was worked with the class of engine described in the Paper (Plate 1, Fig. 2). With the steep gradients on the Carlisle and Crewe section, these engines had been found quite heavy enough for their work, and had during six months kept their running time without any exception. The same train was worked between Crewe and London with the "Bloomer" class of engine, having cylinders 16 inches in diameter with a length of stroke of 22 inches, and 7-feet single driving wheels. The engines weighed rather over 30 tons, and with the more favourable gradients of that section were sufficiently powerful. These engines consumed from 27 lbs. to 28 lbs. of coal per mile run. The loads on the London and North Western railway would be found to be heavier than on the Great Northern railway with the corresponding train.

Mr. Stirling described the method adopted by him for staying fire-boxes. He objected to a flat box, which was a receptacle for mud; but where the box was round, nothing could lie upon it. The material of the stays in the Great Northern railway engines

was Lowmoor chain iron. Although some of the engines had run more than 140,000 miles, none of the tires of the wheels had worn out, and they were still of considerable thickness. With regard to the power of the engine referred to in the Paper, it had taken a train of thirty-three carriages, full of passengers, from Doncaster to Scarborough and back at a speed of about 45 miles an hour.

Mr. W. Adams said, the differences in the designs of the various engines referred to were sufficiently accounted for by the nature of the traffic to be served in each case, the gradients, curves, and the like. He should not care to run a six-wheeled coupled engine with a North London Richmond express train. No doubt such an engine would work the local traffic, but it would not traverse curves in the same easy way as an engine provided with a bogie. He was glad that experiments were being tried with a view to reduce the weight of engines, since the saving of a few tons was a matter of considerable importance. The engines working the Enfield traffic on the Great Eastern line only burned 22 lbs. of coal per mile. They weighed 42 tons, and had four wheels coupled, with a bogie behind. He did not see the advantage of coupling six wheels, as the increased friction would lessen the advantage derived from the diminished weight.

Mr. Thornycroft said, the engines on the South Western line had feed-water heaters; and as their advantage had been questioned, it would be desirable to know the result of their use.

Mr. Crampton said, fifteen years ago he induced Mr. Haswell, of Vienna, to alter the tires of the engines and carriages under his charge, and to give up the plan of having the cone of the wheels all on one side. The wheels, taking everything into consideration, were better cylindrical, as when so formed that shape was retained for the longest time. The hind wheel, in passing round a curve, did not go to the outside, but to the inside, so that the large diameter of the tire was in the wrong place. If the cone was to have any good effect it should be the other way. When the tires were altered, as he suggested, there was a saving of 30 per cent. in the wear and tear. When, however, the French Company took over the line they did not approve of the change, and reverted to the old system.

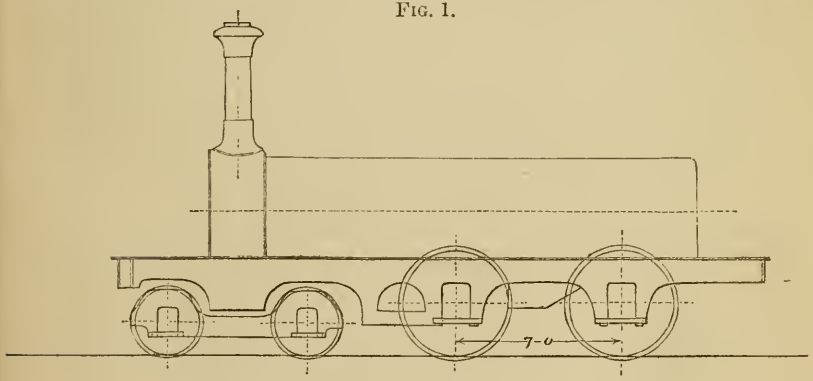
Mr. Edward Slaughter remarked, through the Secretary, that he advocated increased flexibility of wheel-base in all the engines represented, for the purpose of materially reducing the frictional resistance in passing round curves. Experience proved that the tractive efficiency of independent driving axles was much greater

per ton than that of two axles coupled through their four wheels, and four wheels coupled gave a greater tractive result per ton than six wheels coupled. Again, experience also proved, that the greater the contraction of the wheel-base of locomotives, the greater the freedom in passing round curves, and the smaller the frictional resistance. England was the only country in which the long wheel-base was maintained as the rule. All over the Continent the prevailing types were of short wheel-base. In the United States of North America locomotive engines without bogies were almost if not altogether unknown, whether for passenger or for goods trains; and it was sought to contract, as far as possible, the inflexible tractive wheel-base, even at the cost of diminished traction weight. It would, he believed, be found that well-constructed American engines developed greater tractive power per ton, resting on their driving wheels, than English engines having the ordinary long wheel-base. Believing, as he did, the above-cited experience to be sound, and having proved it in many engines designed by himself, he proceeded to apply it to the Great Northern passenger engine. He entirely approved of the substitution of the four-wheeled swivelling bogie for the single straight axle; and should have liked it still better if it had been provided with a traversing as well as with a swivelling movement, which would have given perfect liberty to the engine to adapt itself to any curves. It would probably be replied, that the curves of the Great Northern railway were not such as to require more freedom, but he could not accept that line of argument, which, in any case, was only a question of degree. He firmly believed that the maximum of safety for high speeds was obtained by the greatest flexibility of wheel-base, always assuming that there was maintained in connection with this flexibility a due proportion of rigid wheel-base. He should also have preferred for this engine outside journals for the bogie wheels, for the greater stability of the leading end. For the London and North Western express engine, he should, for the same reasons, advocate a four-wheeled bogie, both traversing and swivelling, in place of the single fixed axle, and he would apply the same principle to the several goods engines described in the Paper, to the extent of reducing the inflexible wheel-base, and carrying a portion of the gross weight upon a radial axle. He believed, in the case of wheel bases of 15 feet to 16 feet, the relative tractive efficiency per ton upon the driving axles was approximately as under :—

Independent driving axle	1·00
Two coupled axles	0·88
Three coupled axles	0·73

He contended that six-wheeled coupled engines were frequently employed where four-wheeled coupled engines would be better adapted to the traffic, and that six-wheeled coupled engines were practically less useful than theory would indicate. In proof of the advantage of a short tractive wheel-base, he would cite a case where, on a line with severe curves and heavy gradients, two classes of engines of identical boilers, cylinders, and wheels had to deal with a normal train of a fixed number of trucks. One engine had six wheels coupled with 14-feet wheel-base, and weighed 33 tons in working order. The other engine had also six wheels coupled with 11-feet wheel-base, and the leading end was carried on a radial axle, bearing 5 tons of the gross weight, 34 tons, leaving only 29 tons for the tractive weight. Each of these engines took the normal train up the heavy gradients, and it was as much as they could reliably do, and through the sharp curves; but the radial engine showed great economy, as compared with the other in diminished repairs of tire, etc., proving the practical value of diminished frictional resistance. In another case the engine, Fig. 1, weighing in working order 36 tons, was

FIG. 1.



Scale $\frac{1}{8}$th of an inch to a foot.

designed ten years ago, for a line with steep gradients and curves of 650-feet radius; but the line having been extended to a more difficult country, resulting in curves of 300-feet and 250-feet radius, these engines were unable to work on the extension, although provided with a swivelling bogie. When, however, the bogie was set aside, and the axles in the same position were made to work radially, but separately, each from their true centres, the engines satisfactorily worked the extension line. This was another proof of the practical effect of diminished frictional resistance obtained by

flexibility of wheel-base. If the above principles were carried into practice, in the case of the usual six-wheeled coupled engines, similar results should follow. He believed if an average English goods engine, with wheel-base of 16 feet, and a running weight of 35 tons, were altered, so that the rigid wheel-base became 12 feet or thereabouts, carrying 30 tons, the remaining weight being carried upon a leading radial axle, that the engine so modified would haul the same load over as difficult grades and curves. If it was replied that engineers would not adopt such proportions for lines having great curvature, he would rejoin that daily experience pointed to the contrary. In any case, if the argument were sound, practice should be conformable, because frictional resistance not only neutralised theoretical traction, but was the measure of wear and tear.

Mr. R. Price Williams regretted that the remarkable points of difference between the Great Northern and the London and North Western engines had not received the attention they deserved, affecting as they did a question of great importance, namely, the working of passenger trains of greatly increased size and weight, due to the carriage of third-class passengers by all express trains on the principal main lines. Mr. Webb, he thought, had given sufficient reasons for the adoption of the four-wheeled coupled engine. He was sorry that Mr. Stirling had not referred to the principles of construction adopted in the Great Northern engine. The Author had stated that the Great Northern engine could draw a load of 356 tons on the level at a speed of 45 miles an hour, and although it was not indicated how that tractive force was arrived at, Mr. Price Williams had been able in an indirect way to deduce it. Multiplying the load drawn, 356 tons, by the full train resistance at the given speed, 30 lbs. per ton, would give the total amount of constant and variable train resistance, equivalent, in this case, to 10,680 lbs., as shown in the tabular statement No. 1.[1] The tractive force at the rails must necessarily

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[1] Engine No. 1.

Weight on driving wheel	15 tons.
Diameter of cylinder	18 inches.
Pressure of steam in boiler	140 lbs.
Mean effective pressure in cylinder, if cut off at about ⅔ stroke	114 lbs.
Length of stroke	28 inches.
Diameter of driving wheels	97 „
Weight of load drawn on the level at a speed of 45 miles an hour	356 tons.

be sufficient at least to balance the amount of train resistance, and the stroke of the piston, the diameters of the cylinder and of the driving wheels, and the full pressure of steam in the boiler being given, the tractive force of the Great Northern passenger engine could be readily found. The Paper stated that the working pressure was 140 lbs., a pressure in the boiler which, assuming the steam to be cut off at $\frac{2}{3}$ stroke, would give an effective pressure in the cylinder of 114 lbs., and, as would be seen from the figures in the table, equal to a tractive force at the rails of 10,662 lbs., or a trifle less than the amount of the total train resistance. Cutting off steam at $\frac{2}{3}$ stroke at a speed of 45 miles an hour was, however, in practice not found to answer, entailing as it did a large amount of waste. Assuming the tractive force required to be 10,680 lbs., it represented nearly $\frac{1}{3}$ of the total weight on the driving wheels, and required a like amount of adhesion. Now an adhesion of $\frac{1}{3}$ was, as had been before pointed out, rarely attainable except under the most favourable circumstances. An adhesion of $\frac{1}{4}$ even was not to be relied on in this country except in very dry weather. In the case, therefore, of the Great Northern engine, notwithstanding an excessive weight on the driving wheels of 15 tons, the tractive force, although largely in excess of the adhesion to be calculated upon in the most favourable weather, and still more in excess of the adhesion obtained in bad weather, was still barely equivalent, with steam cut off at $\frac{2}{3}$ stroke, to balance the train resistance. If instead of this single driving wheel the Great Northern passenger engine had four coupled driving wheels, with the same diameters of cylinders and of driving wheels, and with the same length of stroke, as in the case of the London and North Western

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* (1.) Train resistance on the level at 45 miles an hour, taken at 30 lbs. per ton of load, 356 tons × 30 lbs. = 10,680 lbs.

(2.) Tractive force at rails = $\frac{18^2 \times 114 \times 28}{97}$ (lbs. ins.) = 10,662 lbs. = 4·76 tons.

(3.) Adhesion in average weather $\frac{1}{3}$th of 15 tons . . . = 3·0 tons.
„ „ bad weather $\frac{1}{10}$th „ . . . = 1·5 „

(4.) Estimated load on a gradient of 1 in 200, at a speed of 45 miles an hour—

Train resistance as before . . . . . 30·0 lbs. per ton.
Gradient 1 in 200 = $\frac{2240}{200}$ . . . . . = 11·2 „ „
Total resistance . . . . . 41·2 „ „

Weight of load = $\frac{10,662}{41·2}$ . . . . . = 259 tons.

engine, the tractive force at the rails would amount to 9,946 lbs., equal to 4·44 tons, or $\frac{1}{6}$ of the total weight on the driving wheels, viz., 23 tons, as shown in the tabular statement (Engine No. 1 modified). With this arrangement the ratio between the tractive force at the rails and the adhesion became as favourable as in the case of the London and North Western engine, with the additional advantage of reducing the weight on the driving wheels from 15 tons to $11\frac{1}{2}$ tons. He admitted the force of Mr. Fowler's statement, that steel rails had largely added to the endurance of the road, and that consequently heavier loads might be put upon the driving wheels, but the limits of the endurance of even steel rails were recognisable, and steel rails, which he had thought would have sustained a larger amount of traffic, had already become worn out on portions of the Great Northern railway. Although steel rails of a heavy section (80 lbs. per yard) had been adopted on the Great Northern railway, with a heavier substructure to correspond, he was persuaded that the permanent way, as at present constructed, was not calculated to withstand, for a long period, the destructive effects of the immense weights upon single driving wheels, travelling at the great speeds which obtained on that line, especially on the descending gradients of 1 in 200, from Potter's Bar to King's Cross. The increased cost in the maintenance and renewals of the permanent way, due to the destructive effects of these heavy single driving wheels, would in his opinion more than counterbalance any advantage that could be gained

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ENGINE No. 1 (modified).

If constructed with four coupled driving wheels 6 feet 7½ inches diameter, 17 inches cylinder, 24 inches stroke, } same as Engine No. 2.

The mean pressure in cylinder same as before . . . 114 lbs.

(1.) Tractive force $= \frac{17^2 \times \overset{\text{lbs.}}{114} \times \overset{\text{lbs.}}{24}}{79{\cdot}5} = 9{,}946$ lbs. . . $= 4{\cdot}44$ tons.

(2.) Adhesion: the weight on driving wheels when coupled

becomes $= \overset{\text{t.}}{15} + \overset{\text{t.}}{8}$ . . . . . $= 23$ tons.

Hence, adhesion in average weather $\frac{23}{5}$ . . . $= 4{\cdot}6$ tons.

„ „ bad weather $\frac{23}{10}$ . . . $= 2{\cdot}3$ tons.

(3.) Load drawn on the level at 45 miles an hour $= \frac{9946}{30} = 331$ tons.

(4.) Load drawn on a gradient of 1 in 200 at 45 miles an hour $= \frac{9946}{41{\cdot}2}$ . . . . . $= 241$ tons.

by their adoption. He had ascertained that the 10 A.M. Scotch express from King's Cross had, during the period extending from October, 1872, to the beginning of July, 1873, averaged six carriages and two vans for Edinburgh, and three carriages for Leeds, being eleven vehicles in all. Taking the weight of these eleven vehicles at an average, including live and dead weight, of 10 tons each, that of the engine at 38 tons 10 cwt., and of the tender at 15 tons, the total weight of one of these Great Northern passenger trains would amount to about 163½ tons. Now the total tractive power of the engine on an ascending gradient of 1 in 200, as shown in the tabular statement, amounted to 259 tons; while the same class of engine, with four coupled driving wheels, would still have a tractive power of 241 tons on a similar ascending gradient. With regard to the London and North Western passenger engine, assuming the load carried on a level to be 293 tons, the total train resistance at a speed of 45 miles an hour would, as shown in the tabular statement (Engine No. 2)[1], amount to 8,790 lbs. The tractive force at

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[1] ENGINE No. 2.

Weight on driving wheels	19·75 tons.
Diameter of cylinders	17 inches.
Pressure of steam in boiler	120 lbs.
Mean effective pressure in cylinder, if cut off at about ⅔ stroke	101 lbs.
Length of stroke	24 inches.
Diameter of driving wheels	79·5 „
Weight of load drawn on the level, at a speed of 45 miles an hour	293 tons.

(1.) Train resistance on the level at 45 miles an hour, taken at 30 lbs. per ton of load = 293 tons × 30 lbs. = 8,790 lbs.

(2.) Tractive force at rails = $\frac{17^2 \times 101 \text{ lbs.} \times 24 \text{ ins.}}{79 \cdot 5}$ = 8,812 lbs. = 3·93 tons.

(3.) Adhesion: in average weather ⅕ of 19·75 tons . . = 3·95 tons.
„ „ bad weather $\frac{1}{10}$ „ „ . . = 1·97 „

(4.) Estimated load on a gradient of 1 in 200, at a speed of 45 miles an hour—

Train resistance as before	30·0 lbs. per ton.
Gradient 1 in 200 = $\frac{2240}{200}$	= 11·2 „ „
Total resistance	41·2 „ „

Weight of load = $\frac{8812}{41 \cdot 2}$ = 214 tons.

the rails obtained in a similar way to that already described, and with the steam cut off at $\frac{2}{3}$ stroke, was found to be 8,812 lbs., or a little in excess of the total train resistance, and one-fifth of the total weight of the engine, viz. $19\frac{3}{4}$ tons; giving a fair ratio for adhesion in average weather in this country. But Mr. Webb had informed him, that it was impossible to obtain such useful effects from steam cut off at $\frac{2}{3}$ stroke when travelling at a speed of 45 miles an hour, the steam under these circumstances being cut off at $\frac{1}{4}$ to $\frac{1}{5}$ stroke.

Mr. Hawksley, President, said it might occur to Mr. Price Williams that, when the engine was running quickly, the pressure in the cylinder was so much less than the pressure in the boiler that it need not be cut off at so short a portion of the stroke as was found by the calculation.

Mr. Williams contended that it was only fair to correct an evident misapprehension in regard to the engines designed to work the London and North Western traffic on the Metropolitan District railway, as he could state from his own knowledge that it was in no way contemplated to reduce the power of those engines, but on the contrary their tractive power had been materially increased by utilizing the weight, which in the bogie-wheeled engines on that line was not available for the purpose of adhesion. He might also mention that, by coning the driving wheels in the reverse way to that ordinarily adopted, six-wheeled coupled passenger engines were enabled most effectively to work the heavy express trains (carrying third-class passengers) round the sharpest curves and up gradients of 1 in 75, like that of the Shap incline, at great speeds and with the utmost steadiness and safety. The improvements effected by Mr. Webb and by his predecessor, Mr. Ramsbottom, in the construction of locomotive engines would be admitted. It was at the Crewe works that Bessemer steel had its first trial, both in locomotive construction and for the manufacture of the steel rails now so generally adopted. He believed that at the present time there was no place where Bessemer steel was more largely used, and where its employment in locomotive construction had so much conduced to lessen the weight and at the same time to increase the power of the engines than at the Crewe works.

Mr. Edward Woods said, the great merit of the Paper was its accurate description of some of the best types of locomotive engines in use on the leading railways of this country, and as applied to the transport of heavy traffic on steep gradients. Every one conversant with the history of locomotive engines must

have been struck with the similarity existing between the types of the present day and those of the past. In principle there was very little difference in the construction of a locomotive engine now and that which prevailed twenty-five or thirty years ago. There was the same fire-box, the same tubular boiler, the same arrangements of the cylinders, and the same mode of driving the wheels; the differences being rather in details than in principle. In fact, the principal features which distinguished the newer from the older forms were found to consist in a general enlargement of the several parts, augmenting the power of the engine by increased area of fire-grate and heating surfaces, and enlarged cylinder capacity to correspond, whilst the consequent additional weight imposed on the driving-wheels contributed to afford the needful amount of adhesion. It was, indeed, to be remarked that little variation had been made in the relative proportions, which were now substantially the same as they were twenty years ago. Thus, from a comparison of the working of the best engines at that time he found that, on an average, 1 square foot of grate would burn from $1\frac{1}{4}$ lb. to $1\frac{1}{2}$ lb. of coke or coal per minute, and that 65 square feet of heating surface per foot of grate would effectually and economically absorb the heat generated by its combustion; and the data given by the Author showed precisely the same proportion on an average of the instances cited, namely,

	Sq. Ft. Heating Surface.		Sq.Ft. Grate.
Fig. 1. Great Northern express engine	66	to	1
2. London and North Western ditto	73	,,	1
4. Great Southern and Western of Ireland goods engine	54	,,	1
5. Bombay, Baroda, and Central India ditto	54	,,	1
6. Furness tank engine	76	,,	1
Mean	65	,,	1

Indeed, the discussion had turned chiefly on various points of detail, such as the comparative merits of different methods of staying fire-boxes, the construction of slide-valves, the "Le Chatelier" break, the form to be given to the rolling surfaces of the wheels, &c. Some of the principles of construction referred to in the Paper—such as the mode of framing the engine, the form of the fire-box, the position of the cylinders, whether inside or outside, rectangular boxes and tires, &c., came under discussion twenty or thirty years ago. Mr. Edward Bury, or rather the firm of which he was the head, was the first to introduce the domed and circular fire-box, and also the inside framing,

in contradistinction to the rectangular box and outside framing of Mr. Robert Stephenson. With regard to cylindrical tires, he remembered an engine built by Mr. Robert Stephenson in 1836 or 1837 for the Manchester and Liverpool railway—a six-wheeled coupled engine—which had cylindrical tires on the middle wheels. These central wheels were also without flanges—a method that had been recently advocated by Mr. Webb, who had adopted it in several instances. No doubt, however, some of the features introduced of late years were very important. One of these was the link motion. He could remember the time when there was no other mode of driving than by separate eccentric rods, and the "gab" motion, whether by means of two rods with shifting eccentrics, or by four rods and fixed eccentrics, one pair of each being used for driving forwards, and the other for driving backwards, the "gab" ends of either pair of the rods being brought into gear with the pins on the weigh-bar shafts, as required for reversing or otherwise. The "link" motion had, for a long period of years, superseded the "gab" motion, and seemed to deserve special consideration and notice when treating of the improvements in the locomotive engine; for not only was it in itself a most simple and admirable piece of mechanism, but, in connection with the higher pressures of steam at which the boilers had been worked, it had greatly contributed to increase the duty of the fuel, by enabling the steam to be worked expansively. Its construction was, of course, well understood; but it differed from all preceding agencies in this important respect, that the motion was applied to the valve from a freely-suspended link or bar, the extremities of which were actuated by the rods from two fixed eccentrics, the one giving to the bar a motion suitable for driving the engine forwards, the other giving a motion suitable for driving it backwards, both motions co-existing in whatever direction the engine was travelling. The change as between forward and backward motion was accomplished by raising or lowering the bar (link), or the block, until the latter came into contact with that part of the surface of the link which possessed the particular motion required for driving forwards or backwards, or for cutting off at any desired point of the stroke. The change was smooth and gradual, instead of abrupt and accompanied by shock and risk of breakage, and the link motion thus afforded the fullest control over the working of the engine. Another important feature was the injector, and another the introduction of steel tires, which had no doubt contributed greatly to economy. The "Le Chatelier" break, too, was a modern appliance. A much greater

duty was now obtained from a given weight of fuel than in former years. In 1848, according to observations made by himself on the Liverpool and Manchester railway, the duty performed by 1 lb. of coke amounted to 316,000 foot-pounds, which was equal to the duty of a condensing engine that worked inexpansively at that date. The link motion had not at that time been introduced. Five or six years later, observations made by himself and Mr. Marshall, on the trains of the London and North Western railway, showed the duty as increased to 355,000 foot-pounds. The first result was equal to $6\frac{1}{4}$ lbs., and the second to $5\frac{3}{4}$ lbs. of coke per H.P. per hour. These observations of 1848 and 1853 were the average results of a long series of observations, and took into account the whole of the fuel consumed from first to last. It might be well to analyse the statement in the Paper as to a gross load of 356 tons carried by the Great Northern engine at 45 miles an hour. The consumption of coal was not stated, but it could not well exceed $1\frac{1}{2}$ lb. per square foot of grate per minute, equal to 25 lbs. of coal per minute. Taking the speed at 45 miles an hour and the resistance of the train at 15 lbs. a ton all round, a low estimate, it would be found that 1 lb. of coal had effected a duty of a million foot-pounds, exerting a power of 757 horses; the consumption being only 2 lbs. per H.P. per hour. Few condensing engines working expansively did better; and the statement almost led to the suspicion of some inaccuracy. An experiment which gave such a surprising result deserved to be carefully tested and checked. Indeed, no safe conclusion could be drawn from an isolated instance of this kind. He regretted that the subject of the Fairlie engine had not been more fully brought forward and discussed. Whatever might be its defects, it certainly had the merit of utilising the whole weight of the engine in affording tractive power. There was no doubt some complexity in the construction, but he had been informed by the makers that the difficulties on that score had been to a great extent overcome. He had heard it stated that the engines had worked remarkably well on the Mexican railway. It would be very desirable to have an accurate statement of the work done by them, and the cost, extending over a considerable period. He agreed with Mr. Fowler as to the great difficulties attending the use of six-wheeled coupled engines on sharp curves, unless, indeed, they could be closely coupled, and that would often lead to an inconvenient swaying motion. He had been able to obviate the difficulty in South America on lines where the curves were sharp, the six wheels coupled occupying a very short wheel-base; but in such a case there

was either a four-wheeled bogie or a two-wheeled bogie to carry the leading end of the engine. He had adopted with great advantage the two-wheeled bogie simply to carry a portion of the front weight of the engine, and to steady it. He was now employing such engines on lines in Chili, where the curves were sharp, and the gradients steep; and he was extending the principle by placing a similar pair of radial axles under the foot plate. The bogie engine was almost universal in the United States. Many forms of engine were there adopted — six-wheeled coupled, and eight-wheeled coupled—these being articulated in a particular manner never adopted in this country; but on the whole the preference was given in the United States to four-wheeled coupled or six-wheeled coupled engines, provided with a four-wheeled bogie truck placed under the smoke-box. It was held there that the disadvantage which accrued from diminished adhesion was much more than made up by the lessened friction on the sharp curves and frequently uneven roads.

Mr. Joseph Tomlinson felt disappointed that the practice of the past had not been compared with that of the present. He remembered the early types of engines used in the North, and expected the improvements would have been alluded to. The Author's remark that "as many engineers, so many engines," was hardly fair. Engineers had to make designs for the work required, and it was a sufficient reason for diversity of practice that one engine might be useless where another would do the work. The Paper failed to give the cost of maintenance, though professing to do so, for the very wide differences in the cases quoted were irreconcileable. The diversity of practice on the Great Northern railway and the London and North Western railway was very marked, but he inclined to the engines of the latter as, on the whole, the more useful. As the comparison in the Paper of the engines of these two Companies did not in his opinion take into account sufficiently the difference in the pressures, he had made the following computation :—

London and North Western Passenger Engine.

Tractive power at rail, with 140 lbs. pressure of steam.

20 per cent. cut off . . . . 4,209 lbs.
50 „ „ . . . . 8,403 „

Weight on wheels 20 tons; adhesion 5·4 times.

Great Northern Express Engine.

Tractive power at rail, with 140 lbs. pressure of steam.

20 per cent. cut off . . . . 4,232 lbs.
50 „ „ . . . . 8,928 „

Weight on wheels 15 tons; adhesion 3·75 times.

Considering the small proportion of adhesion in the Great Northern express engine, he thought it would be impossible to utilise its tractive power when in full gear, and that, with a heavy load, the engine could only be started by wire-drawing the steam; whereas in the London and North Western engine, when the rails were dry, the regulator of the engine might be fully opened. With heavy loads the Great Northern engine would take longer to climb a hill, thus entailing an excess of speed in the descent to make up time. There could be no doubt that single engines, when able to do the duty required, would be the easiest on the road, and the least costly to repair and to maintain. Next would be four-wheeled coupled engines, and then six-wheeled coupled engines; as, through inequalities in the material, it was hardly possible to keep all the wheels for any length of time of exactly the same diameter, hence slipping of one or more wheels must result, and the greater the number of wheels coupled, the greater would be the difficulty to prevent this, and the consequent loss of power. He had heard it remarked that, with a heavy weight on the centre wheels, engines were apt to plunge when meeting inequalities on the road; but he thought this was more imaginary than real, as the trailing wheels, being the least loaded, diminished the force of the blow. The plunging could be obviated altogether by inserting a compensating lever between the leading and the driving wheels with equal ends —a practice he always carried out on the Taff Vale railway— and thus giving the same weight on the bearings of each axle. This was nearly the case in the Crewe engine, if the difference in the weight of the wheels was taken into account. The lengthened wheel-base of the Great Northern engine would doubtless conduce to greater steadiness at high speeds on a straight road, but it would be a source of increased wear to the permanent way, where there were curves of short radius; and in that case a high speed would be attended with great damage to the road. A long wheel-base was, for high speeds especially, safer and better than a short one; but still the curves to be traversed must be the guide, and the length could only be fixed as circumstances warranted. Engine and road should each have consideration, and no damage should be done to one at the expense of the other, because they were not both maintained by the same person. A light rolling load on four wheels might do less harm to the road than a heavy weight on two wheels, but any addition to the gross weight to be carried would also cost money, and one must be set off against the other. On the Taff Vale railway, of which he had been the Locomotive Superintendent for eleven and a half years, he found engines with a wheel-base of about 12 feet, which he had altered to 14 feet 8 inches,

the greatest length he thought could be ventured on, the main line having curves of 10-chain radius, and sharper in the sidings. With this length of wheel-base no difficulty was experienced with the flanges of the wheels. He had designed a standard locomotive for low speeds and heavy loads, the maximum load being fixed at eighty empty wagons and a 10-ton break, equal to a gross load of 310 tons, to be conveyed on a line rising 500 feet in 24 miles. On the main line the steepest gradient for any considerable length was 1 in 100. The load was taken up at an average speed of 16 miles per hour. The maximum load down was eighty loaded wagons, weighing 940 tons, at a speed of 12 miles per hour. The engine had six coupled wheels, each 4 feet 6 inches in diameter, the cylinders were 16 inches in diameter with a length of stroke of 24 inches, the pressure of the steam was 140 lbs., and each engine weighed 32 tons. The speeds being low, a large boiler was not wanted; but as weight was necessary, outside frames were used. In this way a large rubbing surface for the axle-boxes, equal to 120 square inches on each side, had been obtained, which kept the boxes from knocking, and when new they were run about 52,000 miles before needing substantial repairs. In addition, the engine could be supplied with better springs, which he considered important both as regarded the engine and the road. The chief difficulty in engines with inside frames only was to get the springs in, and hence substitutes for laminated springs had to be adopted, such as volute springs and india-rubber; but neither resulted in such ease to the road as a good well-proportioned steel spring. As an instance, to show the value of a proper compensating beam, by an index on the leading spring he had found a deflection of only $\frac{3}{8}$ inch in traversing 25 miles. The good state of the road had, however, to share the credit for this. As the engines had both inside and outside frames, he designed a special form of compensating lever, so that both the springs of the driving-axle should act in concert, by making it with two levers at one end. These engines, in full gear, with both sand pipes feeding, and blowing off steam at 140 lbs. pressure on the square inch, had moved backwards one hundred wagons, weighing 1,175 tons, on the level. Often, on ascending the incline early in the morning, both sand boxes had to be used with a weight of 32 tons on the wheels. He calculated the tractive force of the Taff Vale railway engine as follows:—

20 per cent. cut off	. . . .	5,387 lbs.
50 „	„	10,752 „
75 „	„	14,169 „

Therefore, to take a maximum load, including engine and tender, up an incline of 1 in 100 at a speed of 16 miles per hour, a force

must be exerted of 12,104 lbs., equal to a cut off greater than 50 per cent., and showing that to utilise this power, a weight equal to six times the tractive force was needed for adhesion. On greasy rails the speed would be of necessity reduced. He submitted tables (page 46) to show the expense of the repairs and renewal of engines during the time he had been superintendent, in the hope that they might be considered a useful addition to the Paper. He thought they indisputably proved the value of a uniform engine, and of the introduction of improved material. The change from iron tires and axles to others of steel was commenced in 1861; after 1863 no iron tires were used except for tenders; and all engine axles, except cranks, were of either cast or Bessemer steel. He had put in two crucible cast-steel crank axles, which he believed were still at work after eight years' duty of about 20,000 miles a year. The average life of a best Yorkshire crank was about 80,000 miles. The general conclusion to be deduced from the figures was that the sum of 2*d.* per mile would cover the cost of repairs, and that about 0·75*d.* was a fair sum for renewals. The number of engines replaced during the whole period was equal to 4 per cent. per annum, an amount which he considered reasonable.

Being now in charge of the engines on the Metropolitan railway, to which reference had been made, although he had not designed them, he might remark that while always an advocate for light engines, and these were the heaviest he had ever worked, yet he should not deem it advisable to carry the reduction in weight beyond a limit of at most 4½ tons. This must all, or nearly all, come out of the wheels, the frames, and the cylinders. It was admitted that the actual power of the engine was not too great. It followed that the boiler was not too large, as, having to work through the long length of tunnel from Edgware Road to King's Cross, a distance of 2¼ miles, over gradients of 1 in 100, without opening the exhaust pipe, the boiler, unaided by blast, must maintain steam. Then, again, 4 tons of water had to be carried for condensing purposes, and this quantity had proved barely enough for the distance between Moorgate Street and the Mansion House. It followed, that neither the tanks nor the coal bunkers were too large; and condensing-pipes and valves were necessary, and formed a portion of the weight to be carried. He could not agree in the advisability of working such curves as existed on the Metropolitan railway with six-wheeled coupled engines, as he believed any saving that might be effected in the weight would be far more than balanced by the wear and tear of

LOCOMOTIVE EXPENSES, TAFF VALE RAILWAY.

Half-year ending	Number of Engines Maintained.	Mileage of Engines.	Cost per Mile for Repairs of Engines.	Cost per Mile for Renewals of Engines.	Total Cost per Mile for Repairs and Renewals.	Total Cost per Mile of Repairs, Renewals, and Working.	Pounds of Fuel used per Mile.	Engines Renewed.
			d.	*d.*	*d.*	*d.*	lbs.	
June, 1858 . .	44	392,570	3·80	..	3·80	9·16	40·06	..
„ 1859 . .	48	364,781	3·39	1·36	4·75	9·27	29·77	..
„ 1860 . .	48	398,682	2·73	1·40	4·13	8·87	34·09	1
„ 1861 . .	50	429,345	1·84	2·05	3·89	8·78	32·95	2
„ 1862 . .	50	425,690	2·09	1·96	4·05	8·80	33·84	2
„ 1863 . .	50	448,205	1·99	1·86	3·85	8·54	34·25	2
„ 1864 . .	52	500,807	2·00	1·40	3·40	8·54	35·86	1
„ 1865 . .	60	542,534	2·25	0·94	3·19	7·75	33·53	1
„ 1866 . .	67	709,733	1·97	0·81	2·78	7·36	32·82	1
„ 1867 . .	79	744,730	2·00	0·54	2·54	7·52	34·81	..
„ 1868 . .	81	734,881	1·90	0·66	2·56	7·72	33·97	..
„ 1869 . .	81	759,363	1·54	0·36	1·90	6·93	34·77	..
Average . .		537,609	2·29	1·21	3·50	8·27	34·23	
December, 1858	46	381,008	4·14	0·55	4·69	9·36	29·10	..
„ 1859	48	400,228	3·42	1·00	4·42	8·67	29·88	1
„ 1860	50	412,737	2·22	2·04	4·26	9·19	34·97	1
„ 1861	50	419,917	2·10	2·09	4·19	8·85	32·51	1
„ 1862	50	453,733	2·57	1·81	4·38	8·33	33·47	2
„ 1863	50	470,490	2·71	1·50	4·21	8·63	34·64	1
„ 1864	54	531,260	2·08	1·37	4·17	8·27	32·50	2
„ 1865	63	610,447	2·05	1·07	3·12	7·66	31·53	1
„ 1866	73	749,406	1·81	0·83	2·64	7·41	33·28	1
„ 1867	79	777,356	2·16	0·77	2·93	7·98	33·29	2
„ 1868	81	755,663	2·15	0·77	2·92	7·99	33·20	2
Average . .		542,022	2·49	1·25	3·74	8·39	32·57	
Average for June — half-years . .		537,609	2·29	1·21	3·50	8·27	34·23	
Average for Dec. —half-years		542,022	2·49	1·25	3·74	8·39	32·57	
Average for 11½ years .		539,815	2·39	1·23	3·62	8·33	33·40	

the road. Even now, with a rigid wheel-base of only 9 feet, the entrance of curves was sensibly felt, and any alteration should be in the direction of shortening the rigid base. The argument, that because the engine was too heavy for the duty required on the London and North Western railway therefore it was too heavy for the Metropolitan railway failed, as in the former case the load was only 52 tons, while in the latter it was 120 tons carried up gradients of 1 in 70. Just to move this train on a gradient of 1 in 70 required a tractive force at the rails of 6,000 lbs; and as a sudden strain was required at starting, equal to double that power at least, great adhesive force was necessary, as the trains stopped and started twenty-one times in fifty-five minutes in a distance of 11 miles. He had ascertained that the weight of the engine quoted by Mr. Fowler was correct, viz., in working order, 42½ tons.[1] He estimated the tractive power at the rails of these engines, with a pressure of 130 lbs. in the boiler, at

20	per cent.	cut off	. . . .	4,419	lbs.
50	„	„	. . . .	8,820	„
75	„	„	. . . .	11,625	„

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[1] Extract from letter from Messrs. Beyer, Peacock, and Co. :—"The first lot of tank locomotive engines we constructed for the Metropolitan Railway Company, numbered 1 to 18, weighed as follows:—

	In working order, with full water and coal tanks and a good fire.			Empty.		
	Tons.	cwt.	qrs.	Tons.	cwt.	qrs.
Weight on the four bogie wheels . .	11	3	2	10	15	2
„ „ driving wheels. . .	15	9	2	12	3	2
„ „ trailing wheels . .	15	10	0	12	9	3
Total . . .	42	3	0	35	8	3

These engines had coal tanks 18 inches wide, but in the next lots made, numbered 19 to 23, 24 to 28, 29 to 33, and 39 to 44, the coal bunkers were increased in width from 18 inches to 2 feet 6 inches. Some other slight modifications were also introduced which brought the weight up to—

	In working order.			Empty.		
	Tons.	cwt.	qrs.	Tons.	cwt.	qrs.
Weight on the four bogie wheels . .	10	5	0	9	9	1
„ „ driving wheels . .	16	11	3	13	12	0
„ „ trailing wheels ' . .	15	15	1	12	13	2
Total . . .	42	12	0	35	14	3

In the last engines we built for the Company, numbered 45 to 49, the coal tanks were reduced in width from 2 feet 6 inches to 2 feet, and their weight would be about the mean between the others."

Therefore, with 32 tons on the two pairs of driving wheels, this weight gave 6·1 times the tractive power at the maximum. He should not consider less than 5 times sufficient: so the excess of weight of the engine was only 5 tons on the driving wheels according to his computation.

During the discussion mention had been made of the counter-pressure break of M. Le Chatelier. He considered it wrong in principle to apply break power in such a way. As the steam could only reach the piston to retard it when at half-stroke, it followed that a blow equal to the pressure at least, multiplied by the velocity of the piston, must be given with destructive effect on the moving parts. A greater result could be obtained by applying a break at the circumference of the wheel, and just as quickly. Mention had also been made as to the use of double-ported slide valves with short travel. He might say that the whole of the engines designed for the London and South Western railway by Mr. John Gooch, with whom he had served from 1846 to 1850, were so fitted; a back plate on the valve being the means of closing the inner ports. His experience of them was not favourable, as they gave much trouble to keep good; and he believed that Mr. Gooch did not continue to use them on the Great Eastern railway. He had no doubt that the plain valves, now generally adopted, were the best; in practice they would run 50,000 miles without leaking. He believed that balancing the reciprocating parts of locomotive engines was partially done so far back as 1840, by Messrs. Sharp, Roberts, and Co., whose engines were the first he could remember with balance weights. The same was effected perfectly at Crewe in 1850, and on the Midland, after he had joined that railway, in 1854. It would be highly interesting and a guide to more correct practice, if accurate data could be obtained from the indicator of the actual duty done over various lines of railway by the engines in use. This he should much like to assist in; and with the co-operation of other locomotive engineers, no doubt good results would accrue.

Mr. H. Appleby said, as a locomotive superintendent, he naturally took great interest in the subject under discussion. It had been contended that the six-wheeled coupled engine was well adapted for working heavy gradients with sharp curves, and a comparison had been made as to the relative merits of the six-wheeled coupled goods engine and the four-wheeled coupled passenger engine for a traffic equal to the Metropolitan. As a practical railway man, with twenty-four years' experience, he differed entirely from Mr. Webb and Mr. Stroudley as to the kind of engine for that class

of traffic. He was now connected with the Monmouthshire railway, where there were curves of 5-chain radius, and where passenger traffic was conducted over gradients of 1 in 42. He thought, when he saw a bogie engine on the line, that it would be suitable for the traffic; but it was not equal to the work. With regard to the six-wheeled coupled engine for 5-chain curves at a speed of 25 miles an hour, he felt compelled to condemn it, and to substitute an engine of another class. After experimenting several days with a North London engine, he was convinced that that would best meet his requirements. It was only within the last ten or twelve years that the bogie truck had been used to any extent in this country, although it was well known by English engineers that it had been adopted in America on all the railways, both for engines and carriages, from an early date. Its introduction in American practice was no doubt the result of necessity, and quite as much for the purpose of safety in running over the rough lines of that country as for taking the curves. The flexible character of American engines enabled the bogie with a fixed centre to run round sharper curves than the more rigid English type of engine could be expected to pass with a similar arrangement of bogie frame. To overcome that difficulty, Mr. Bissell introduced a bogie with a radiating arm, the centre of which was behind the bogie frame. It had lateral motion, controlled by inclined planes, to bring back the engine to a central position on a straight line. This bogie did not allow the wheels to radiate properly in going round curves, and it had a jerky, unsteady motion, arising from the action of the inclined planes, and the want of an elastic bearing. These defects led Mr. Adams, M. Inst. C.E., to design a bogie that would be free from such objections, and it had been adopted on some of the principal railways in this country. This bogie truck was of very simple construction. The principal features were a central sliding block resting on two bearers attached to the bogie frame, and bogie pin resting on a circular india-rubber cushion, which yielded by its elasticity to the varying positions of the bogie frame, whether arising from the curves or the irregularities of the road, or the super-elevation of the outer rail. It was, in fact, essentially an elastic bogie. There was abundant practical experience to show, that four-wheeled coupled engines, with bogie trucks having a proper lateral motion, would on lines with sharp curves draw a greater load than ordinary six-wheeled coupled engines of the same weight, when all the weight was available for adhesion. The explanation was that the power of the

latter was largely absorbed in overcoming their own friction. As an illustration, a short time ago, on the Monmouthshire railway, a six-wheeled coupled goods engine, with cylinders 16 inches by 24 inches, and wheels 4 feet 9 inches in diameter, came to a stand, with steam blowing off at 140 lbs. per square inch on a 10-chain curve, with eleven coaches and a van. While in this position, an engine with Mr. Bridges Adams's bogie, having cylinders of the same dimensions, but with wheels 5 feet in diameter, and the same weight of train behind it, came up and pushed the former engine and its train out of the way, with the assistance of the leading engine. He considered that the saving of friction in the bogie engine, as compared with that of the six-wheeled coupled engine, was equal to an additional load of four or five coaches. Many illustrations of a similar character could be given to show the superiority of the bogie engine in saving friction over the six-wheeled coupled engine. In consequence of this, the wear and tear of tires and of the permanent way were considerably less with bogie engines than with engines having a rigid wheel-base. As the sharpest curve on a railway determined the wheel-base of an engine, so also the heaviest gradient ruled the load that could be taken over the line. The Monmouthshire Company's lines of railway running out of Newport were designated the Eastern and Western Valleys, the line from Newport to Blaenavon being termed the Eastern Valleys. The sharpest curve on the main line in this section was of 6-chain radius, and the ruling gradient was 1 in 42. On the Western Valleys line, starting from Newport, and terminating by a junction from Aberberg, the ironworks of the Ebbw Vale Company were reached on one side, and those of the Nantyglo and Blaina on the other. The curves on the Western Valleys section, 21 miles and 12 chains in length, were more severe than on the Eastern Valleys; the gradients, however, were somewhat less, the sharpest being 1 in 53. On joining the service of the Monmouthshire Railway Company, about six years ago, he found there were three different classes of passenger engines in use, not one of which gave satisfactory results in conducting the traffic. On the Eastern Valleys section there was a four-wheeled coupled six-wheeled engine, constructed by Messrs. Sharp, Stewart, and Co., and a four-wheeled coupled engine with a four-wheeled bogie constructed by Messrs. Stothert, Slaughter, and Co. The difficulty experienced in working the former engines was to keep the leading wheel flanges from becoming knife-edged: in fact to keep the engine in safe working order, the tires had to be turned up after running a distance of 10,000 miles. The four-wheeled bogie engine was of a similar type

to those he had been accustomed to on the Great Western and the South Devon railways, having the bogie in front, as well as to the bogies fitted at both ends of the engines on the Bristol and Exeter railway, which latter had also a large pair of driving wheels in the centre. He had travelled on the latter engines at a speed of 75 miles per hour with perfect steadiness and safety. The manner in which those engines passed round sharp curves at excessively high speeds, and the small amount of repairs they required, convinced him, while employed by that Company, that for working a railway where sharp curves abounded, no other class of engine was so well suited as a bogie engine for safety and economy, both in regard to the locomotive and to the permanent way. He naturally felt pleased at having a bogie engine to work the passenger traffic, which engine he then considered well adapted for sharp curves. He soon, however, discovered that, as the curves he had been accustomed to were not nearly so sharp as those on the Monmouthshire railway, the wear of the bogie flanges, as compared with that of the leading wheel of Messrs. Sharp's engines, was much less, but the lining up of the axle brasses of the bogie engines, to correct the end play in the journals, required nearly as much attention as those in the rigid wheel-base of Messrs. Sharp's engine. This difficulty, however, was much greater on the Western Valleys section, which was worked by two light six-wheeled coupled tank engines. Not only were these engines totally unsuited for the traffic, but they were unfit to pass round the sharp curves at a speed of 25 miles per hour, and were destructive to themselves, as well as to the permanent way. This state of things led him to consider what was the best class of engine to work the line safely, the three types he had being practically useless. He first examined the locomotives of the Metropolitan railway, and found them much better adapted to the traffic of the Monmouthshire railway than any engines in the possession of that company. He then visited the North London railway, and rode on engines fitted with Mr. Adams's bogie. After several trial trips and repeated experiments, he found that Mr. Adams's bogie engine was the most simple, and the best adapted to the requirements of the Monmouthshire railway of any he had seen. The first bogie he designed on Mr. Adams's principle, five years ago, had not in the slightest degree been departed from in more recent engines, as he found it all that was necessary for working the traffic. The question of curves with these engines was now a matter of no consideration. The wear of the flanges of the wheels and axle brasses was so slight, that were it not for the tread

of the tires wearing, turning up the flanges would entail the smallest proportion of the expense of maintenance, whereas with the former engine it was one of the largest items. The cost of maintenance of these engines was less than of any type of engines he previously had under his charge; their consumption of fuel, as taken from the monthly abstract sheets, was 24·48 lbs. per mile run; the weight on each wheel in working order was—trailing wheels 14 tons, driving wheels 14 tons, and bogie 12 tons. The great flexibility of this engine, with the 12 tons' weight alluded to on the bogie, made it really more powerful in drawing a load round the curves than a six-wheeled coupled goods engine, with the whole weight available for adhesion. He was so satisfied on this point, that he was now substituting four-wheeled coupled bogie engines for six-wheeled coupled engines, for the purpose of working goods traffic. This latter type of engine had 30 tons on the coupled wheels, and was replacing six-wheeled coupled engines, the total weight of which was 30 tons.

Mr. Robinson replied, through the Secretary, that the Le Chatelier break had been found inconvenient on several English railways, though the plan suggested of injecting water into the steam chest had been adopted. On the other hand, Messrs. Sharp, Stewart, and Co. were now building twenty engines for the Midland Railway Company, in all of which the counter-pressure break was to be applied. With regard to the remarks as to bogie engines in comparison with rigid coupled engines, on several large English railways, the grinding effect upon the extreme wheels of coupled engines had been much diminished by the sliding axle-box described in the Paper (Plate 1, Fig. 7). This would favour the experience of Mr. Stroudley and the suggestions of Mr. Webb; but the main question on these points seemed to be, did the manifest advantages, as to diminished tire friction, obtained in the bogie system, compensate for the greater weight, the more complex structure, and the loss of adhesion which must exist in a locomotive made with a bogie of whatever kind? Experience alone could decide the question.

Mr. Brunlees remarked, through the Secretary, that it was, he thought, much to be regretted that the discussion had been almost entirely confined to points of detail of some particular engine, instead of to the general principles of the various types. A comparison of the two examples of passenger engines given in the Paper would show, that to utilise the full steam power of the Great Northern engine, the adhesion must be equal to $\frac{1}{4}$ of the weight upon the

driving wheels, while the full steam power of the London and North Western engine would remain effective till the adhesion fell to about $\frac{1}{7}$. The consequence was, that if the adhesion were as low as $\frac{1}{5}$, which was often the case, the North Western engine would still be taking a load of 293 tons at the speed of 45 miles an hour, while the Great Northern engine would only take a load of 278 tons at that speed. This demonstrated the great advantage of having a reserve of adhesion by means of coupled wheels. There was also to be remembered the wear and tear of the road occasioned by large engines, which imposed a stress of $7\frac{1}{2}$ tons per wheel, with a less effective result than one with only 5 tons on each driving wheel. It was all very well to increase the strength of the road, to make it equal to the passage of an excessive weight at a high speed, but it was at least more economical to render this unnecessary.

Mr. Druitt Halpin observed, through the Secretary, that some statements had been made during the discussion with which he could not agree. Mr. Bramwell had exhibited a drawing of a double-ported or gridiron slide valve arranged for locomotives, and had asked why such a valve was not used, as it reduced the travel to one-half. At the meeting of the Institution of Mechanical Engineers, held at Birmingham in January, 1871, in answer to the same question, during the discussion of a Paper on balanced slide valves for locomotives, the president, Mr. Ramsbottom, had said that the reason this description of valve was not used was that the variation of the lead, quite irregular enough with the present arrangement, would become much more serious if the travel of the valve were reduced to one-half.[1] An additional reason why the proposed arrangement had not been adopted, perhaps, was that, with such excessively short travels, the error, almost inseparable from the wear of the pins, &c., in the link motion, would be much greater. He might state, with reference to Mr. Reynold's calculations, that a series of experiments, made by Bauschinger on the Bavarian railways, showed that out of eight passenger engines the consumption of water per I.H.P. per hour averaged 31·575 lbs., the minimum being 26·1 lbs., and the maximum 35·6 lbs.[2] Now if it be assumed that the distance from London to Peterborough was 75 miles, and that the journey was made in an hour and a half, the speed would be 50 miles per hour, and, taking the consumption

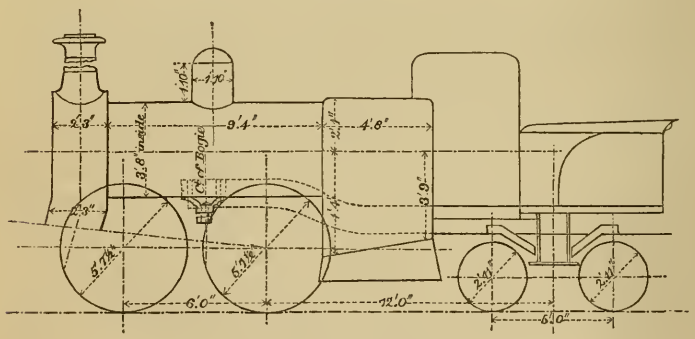
[1] *Vide* Inst. of Mechanical Engineers. Proceedings 1871, pp. 45, 46.

[2] *Vide* "Indicator-Versuche an Locomotiven," von Joh. Bauschinger, p. 118. 4to. Leipzig, 1868.

of water in pounds per I.H.P. per hour as being only 30, then $678 \times 30 \times 1{\cdot}5 = 30{,}510$ lbs. = 3,051 gallons; but as the maximum quantity of water contained in the tenders was only 2,700 gallons, the I.H.P. would be only 600, assuming the same consumption of water. But the consumption of fuel, as recorded at 27 lbs. per train mile, gave 1,350 lbs. per hour at a speed of 50 miles; and as the maximum quantity of water evaporated was 18,000 lbs., the result was an evaporation of 13·33 lbs. of water per 1 lb. of fuel.

Mr. A. McDonnell furnished, through the Secretary, an account of the performance, for the year 1873, of two double bogie Fairlie engines on the Great Southern and Western railway of Ireland. The engines had one pair of 15-inch cylinders with four wheels coupled, the wheels being 5 feet 6 inches in diameter. The tank was carried on a small bogie behind. The weight of the engine was 20 tons on the coupled wheels, and 16 tons on the hind bogie. Engine No. 33, Fig. 2, had not received a general repair during

Fig. 2.



Scale $\frac{1}{8}$th of an inch to a foot.

the year, but No. 34 had. A section of the leading tires of No. 33 was shown in Fig. 3. (See page 55.)

	No. 33.	No. 34.
Miles run	30,977	22,738
Coal used	19·8 lbs. per mile.	21 lbs. per mile.
Wages for repairs	0·19*d.* ,,	0·50*d.* ,,
Materials	0·40*d.* ,,	1·08*d.* ,,
Average load, six-wheeled carriages	6·1	7·9

Mr. G. H. Royce stated, through the Secretary, that the "Fairlie" class of engines on the Festiniog line consumed 25 per cent. less

fuel per ton per train mile and took double the load of the ordinary engines, whilst the cost of repairs was less than for two engines of the latter type. On the Great Luxembourg railway, the "Engerth"

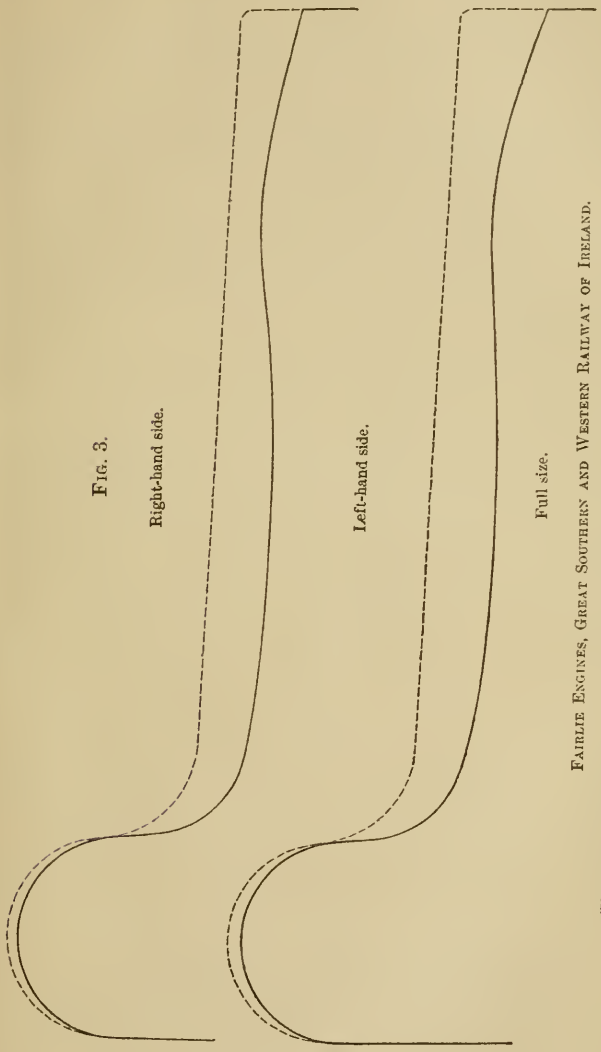


FIG. 3.

FAIRLIE ENGINES, GREAT SOUTHERN AND WESTERN RAILWAY OF IRELAND.

Full size.

The dotted lines show the original thickness of tire. The tires have been turned over and have run 46,034 miles.

engines, when engaged on main-line traffic, consumed 0·08466 kilogramme of fuel per ton per kilometre, while the "Fairlie" engines consumed only 0·06775 kilogramme per ton conveyed for the same

distance. When employed on branch-line traffic the "Fairlie" engine consumed 0·06936 kilogramme of fuel per ton of train per kilometre, as compared with 0·10296 kilogramme consumed by the two ordinary engines employed to do similar work. Thus the consumption of fuel by the "Engerth" engines on main-line traffic was 25 per cent. in excess of that by the "Fairlie" engines; and on the branch-line traffic the excess reached 48 per cent., while the cost for wages was 100 per cent. greater. Again, on main-line traffic the loads taken by the "Fairlie" engines were 33 per cent. in excess of those of the "Engerth" engines, while on the branch traffic two engines were employed to do the same work as one double-boiler double-bogie "Fairlie" engine. Satisfactory results had also been obtained by the use of the "Fairlie" engine on railways in Peru, New Zealand, Russia, Canada, Mexico, Venezuela, Sweden and Ireland.

Mr. Alfred Rumball remarked, through the Secretary, that, as Engineer to the Government Railway Commissioners of the Argentine Republic, he had been requested to advise as to the desirability, or otherwise, of employing steel plates, instead of the best Yorkshire iron, for the boilers of the locomotive engines for the Cordoba and Tucuman railway. He did not feel justified in recommending steel for the following reasons, viz.:—1st. The very uncertain nature of the material, and the difficulty of obtaining it of regular uniformity, and sufficiently homogeneous. 2ndly. From the fact that bad water would have a more deleterious effect upon steel plates than on iron, and that steel plates would be more liable to crack under unequal or sudden changes of temperature. 3rdly. From an economical point of view, as in the event of failure of the boiler, it would be difficult and expensive to renew the steel plates; whereas iron was more easily worked, and could be procured at any commercial centre. His advice had been adopted by the Argentine Government, who finally decided against the use of steel boilers for the engines of the Cordoba and Tucuman railway. The testing of steel at the present day was very difficult; not so iron. He had little doubt, however, that steel would eventually be largely used for boilers, when it could be manufactured of an unvarying quality, and when reliance could be placed upon the mode adopted for testing. For this end, and with a view to the proper control of the manufacture, he understood that a large railway company, and one of the principal constructive departments of the English Government, contemplated the establishment of works on their own premises for the manufacture of steel. In the United States, in 1870, the American Railway Master

Mechanics' Association ascertained, in reply to inquiries from the principal locomotive superintendents of the main lines, that very few favoured the idea of substituting steel for iron for the outside shell of locomotive boilers. Among the locomotives exhibited at the Vienna Exhibition in 1873 only one or two were provided with steel boilers, a fact which might be regarded as an index of continental practice.

Mr. P. Stirling observed, through the Secretary, that he had constructed two classes of engine for passenger trains, one class with four wheels, 6 feet 6 inches in diameter, coupled; the other with a pair of 7-feet driving wheels. Both engines had similar boilers, and cylinders 17 inches in diameter with a length of stroke of 24 inches; the pressure of steam in the boilers was 140 lbs. On his frequent journeys from London he had been in the habit of noting the size of the trains and of the class of engine used. He found that with a similar train in both cases the single engine had fully the best of it, in fact, generally beat the coupled engine in time to Potter's Bar, a distance of nearly 13 miles, and nearly all up hill, the gradients varying from 1 in 105 to 1 in 200. This led him to think that sufficient adhesion could be got with a single pair of driving wheels, and he believed no one would doubt the superior freedom and economy of a single engine over a coupled one. He considered the usual cylinder power was quite inadequate to the required adhesion in nearly all engines. In designing the engine under consideration, he determined to have a large wheel, being satisfied that the larger the wheel, the better the adhesion to the rail; and as inside cylinders could not be used, in consequence of the height of the cranks, he put them outside, where he could get them between the wheels of the bogie and in a horizontal line with the centre of the driving wheel. The tractive power of this engine, by calculation, was 15 per cent. more than that of the coupled one, and in practice it performed proportionately more work. It conveyed trains of from sixteen to twenty-six carriages from King's Cross with ease, and on several occasions twenty-eight had been taken and time kept; so that the pulling power of the engine was established. No doubt existed as to its running powers, a distance of 15 miles in twelve minutes having been accomplished with a train of sixteen carriages. The engine had been perfectly satisfactory in all respects, and more of them were in course of construction. As to its economy in repairs, five of them had run half a million miles, and had cost 1·21*d.* per mile, a much larger sum than the London and North Western coupled engine, which was said to have worked over six and a half years at ½*d.* per mile; but running shed

repairs must have been meant, as that was just the sum the Great Northern engine cost for these repairs. On referring to the railway reports for last half-year, he found the average cost for renewals and repairs of engines on the London and North Western railway had been 3·16*d.* per mile, and on the Great Northern 3·05*d.*, so that there was not much difference between the two. During the last eight years the Great Northern Company had renewed to the extent of 10 per cent. per annum, equal to renewing the whole engine stock of the Company every ten years. As to economy in running, it had been stated that the Great Northern engine took trains of sixteen carriages on a consumption of 27 lbs. of coal per mile, including lighting up, &c. In October last, the average consumption of fuel, with an average load of eleven carriages, was 23 lbs. per mile, a duty which he did not think could be surpassed—certainly not with coupled engines. It might be said that a few pounds of fuel per mile was no great matter, but 1 lb. per mile on the Great Northern mileage per annum represented a sum very little short of £5,000, and a few pounds would make up a large sum. The large engines were constantly employed on express trains, running from 45 to 50 miles an hour. It had been said the weight on the driving wheels (15 tons) was excessive, and would be destructive to the permanent way; but such was not the fact as reported to him by the engineers of the line. The bogies in front carried a comparatively light weight on each wheel, but quite sufficient to solidify the road before the driving wheels came on the rails, and thereby put it in the best position to carry the weight of the large wheels. The engines seemed to have plenty of adhesion for the size and power of the cylinders, and did not slip more than coupled engines under similar circumstances; and, with a slight application of dry sand, slipping was entirely prevented. Powerful passenger engines were a necessity on the Great Northern railway, from the undulating nature of the road, scarcely any part of the main line being level, and the ruling gradients were 1 in 200 throughout, except out of King's Cross, where there was a length of 1½ mile, with a gradient of 1 in 105. The weight of trains also varied very much; and as it was not the practice to put more than one engine on the train, that one must be able to take whatever offered. The assisting mileage did not exceed 150 per week, and was chiefly incurred in the Leeds and Bradford districts in helping heavy mineral trains over gradients of 1 in 50.

November 18, 1873.

T. HAWKSLEY, President,

in the Chair.

The discussion upon the Paper, No. 1,369, "On Modern Locomotives," by Mr. J. Robinson, was continued throughout the evening.

November 25, 1873.

T. HAWKSLEY, President,
in the Chair.

No. 1,347.—"Account of the Construction and Maintenance of the Harbour at Braye Bay, Alderney." By Leveson Francis Vernon Harcourt, M.A., M. Inst. C.E.[1]

The attention of the Government having been directed, in 1842, to the defenceless state of the Channel Islands, and to the necessity for harbour accommodation, the late Mr. James Walker, Past-President Inst. C.E., was requested by the Admiralty, in 1844, to examine and report on the proper sites for, and on the cost of, the proposed harbours. These investigations resulted, in 1847, in the commencement of two harbours, one at St. Catherine's Bay, Jersey, the other at Braye Bay, Alderney, for which designs were furnished by Mr. Walker.

At first it was only contemplated to construct, at Alderney, a small harbour, sheltered on the south and south-east by the island, and on the west and north-east by two breakwaters, one commencing at Grosnez Head and the other at Roselle Point. The area thus proposed to be inclosed comprised about 67 acres of water surface, of a depth of 3 fathoms and upwards. This plan was subsequently enlarged, by successive Boards of Admiralty, till the scheme consisted, in 1858, of a harbour of 150 acres, with a depth of 3 fathoms and upwards, the maximum depth being 20 fathoms at low water of ordinary spring tides. The greater portion of the western breakwater, forming part of this scheme, has been carried into execution; but the projected eastern breakwater was never commenced. (Plate 2.) The harbour is therefore sheltered on the west, south, and south-east, but is open to the north-east, and is more or less exposed to the winds blowing from the points of the compass between north-north-east and east-south-east. Westerly winds are the most prevalent in the locality, and westerly gales are much more frequent and severe than easterly

[1] The discussion upon this Paper extended over portions of two evenings, but an abstract of the whole is given consecutively.

gales.[1] The sea raised by westerly storms is very high, that part of the Channel being open to the Atlantic Ocean; whereas the waves caused by easterly gales, acting only on the confined waters of the English Channel, are comparatively small. The disturbance of the sea at Alderney during storms is increased by the very rapid tides, occasioned by the great body of water that at every tide passes and repasses through the narrow, and in parts shallow, channels which adjoin the island, owing to the peculiar heaping up of water in the bay of St. Malo. The rise of ordinary spring tides at Alderney is only 17 feet, whereas at Jersey it is 33 feet, and at St. Malo 36 feet. The great body of water thus accumulated in the bay finds its chief entrance and exit through the Race of Alderney and the passages between the rocks to the west of the island, the spring tides running in some places at the rate of 7 or 8 knots an hour.

The force of the sea during storms in this part of the channel, owing to these causes, and the exposed situation of the proposed harbour, was not understood at the commencement of the works. The first design (Plate 4, Fig. 1) consisted of a mound of rubble stone, surmounted by a superstructure. The superstructure was founded at the level of low water of ordinary spring tides, and was composed of two separate walls, one on the sea side and the other on the harbour side, intermediate space being filled with loose rubble stone. The sea wall was 14 feet thick, with a batter of 9 inches in a foot; it was built without cement up to 4 feet above high water,[2] with large undressed stone (the largest stones being used for the face), laid as close together as possible. The harbour wall was 12 feet thick, with a batter of 4 inches in a foot; it was built of dry masonry up to 4 feet above high water. On the top of the sea wall the outer wall of the promenade was built of masonry set in mortar. The inner wall of the promenade rested on the rubble filling between the sea and the harbour walls; and the space between the two promenade walls was filled with loose rubble stone, the whole forming the base of the upper or promenade level, which was 15 feet wide. This upper structure served as a protection for the lower or quay level, which was about 29

[1] From daily records kept at Alderney for twenty-two years, it appears that the proportion of westerly winds to easterly winds is as 3 to 2; and the proportion of days of westerly gales to those of easterly gales as 5 to 2. *Vide* Appendix, pp. 80–83.

[2] Whenever the levels of high water and low water are mentioned, they are to be understood as referring to the levels of high and low water of ordinary spring tides. The difference between the two levels is 17 feet.

feet wide. The roadways, on both levels, were paved with granite coping and pitching. The upper roadway was protected, on the sea side, by a small parapet, 4 feet high and 4 feet wide, of native stone, coped with granite.

The abundance of stone on the island rendered the '*pierres perdues*' system very suitable for the foundations of the breakwater; and this mode of construction (Plate 3) was specially applicable in the great depth of water subsequently attained. A considerable area of land having been purchased by the Government at Mannez, on the north-east side of the island, a quarry was opened, and a railway constructed to convey the stone to the works, a distance of about 2 miles. The material is a hard sandstone known as quartzite. An opinion was obtained from Hugh Miller, that "It would be very suitable for harbours or the ring stones of arches, or, in short, for any work in which strength rather than minute finish would be the desideratum" —an opinion which time and experience have fully confirmed. The breakwater, at its junction with the shore, is about 180 feet wide, and has a slipway on the harbour side for the accommodation of vessels at any state of the tide. The width rapidly contracts to the section just described, in accordance with which design it was commenced in 1847.

It became evident, however, after the experience obtained by the resident engineer, Mr. William Parkes, M. Inst. C.E., of the effect of storms in that locality during two winters, that the sort of work proposed, though suitable enough in other situations in the Channel Islands, was quite inadequate to resist the force of the waves at Alderney. The rubble base had in several instances been disturbed, and, during storms, portions had been washed into the harbour, while considerable damage had also been done to the sea and harbour walls in progress. The small pier of an old harbour, previously existing in Braye Bay (Plate 2), was indeed built in the same manner, and some grounds were thus afforded for the supposition that such a work might stand; but it was very little exposed, and extended only a short distance from the shore.

Accordingly, in the spring of 1849 alterations were made—thus the joints in the face of the uninjured portion of the sea wall, already built, were filled with Medina cement, loose stones were removed, the masonry of the sea wall was from that period set in cement in regular courses, and the bed joints of the face work dressed; the batter of the face was gradually reduced from 9 inches to 6 inches in the foot; and it was determined to commence the foundations of the superstructure at a lower level.

The foundations of the sea wall had been carried as far as 410 feet from the shore by the autumn of 1849, the first 150 feet having been sounded at low water, and the remainder as low as practicable without the aid of diving apparatus.

The mass of stone, forming the base, had, up to this time, been tipped from the end of the bank, in the line of the proposed breakwater; but, as hopper barges were to be used for depositing the stone for the future, some place of shelter had to be provided for them. A small inner bay, close to the works, was converted into a harbour, by the construction of two short piers, 250 feet and 100 feet long respectively, with an opening between them of 45 feet (Plate 2). The area thus inclosed was about $1\frac{3}{4}$ acre. The bottom was excavated to low-water level, and a quay was formed round it. This harbour has proved of great service for vessels unloading cargoes, both for the works and for the general trade of the island, in addition to the special purpose for which it was constructed.

As it was found that the mound of rubble stone, forming the base of the breakwater, was not disturbed by the sea at a greater depth than 12 feet below low water, it was determined to commence the foundations of the superstructure at that level. As soon as diving apparatus and the hopper barges were procured, the work was proceeded with in accordance with the amended designs.

The designs were furnished by Messrs. Walker and Burges; and, on the resignation of Mr. Parkes at the close of the year 1849, the late Mr. Thomas Rhodes, M. Inst. C.E., was intrusted with the superintendence of the works as resident engineer, in which duties he was ably assisted by Mr. James May, M. Inst. C.E., who, in 1859, succeeded to Mr. Rhodes' office, and continued in sole charge of the works till 1870, when he left for Egypt to conduct the harbour works at Alexandria.

Messrs. Jackson and Bean were the contractors from the commencement of the works. In 1851 a fresh contract was entered into with them, which continued in force, with certain modifications, up to February, 1872, when their contract was finally brought to a close. They were represented at Alderney, successively, by their agents—Mr. Thomas Dixon from the commencement till 1857—Mr. John Jackson from 1857 till 1866—and Mr. William Read from that time till the end.

A section of the second design for the superstructure is shown on Plate 4, Fig. 2. It consists of a sea wall and of a harbour wall, with filling in the intermediate space, surmounted by a

promenade wall. It has therefore two roadways, one on the upper or promenade level, and the other on the lower or quay level, as in the first design; but the parapet on the sea side of the upper level was subsequently abandoned, after having been built to a distance of 231 feet from the shore.

The sea wall was commenced on the top of the rubble base, at a depth of 12 feet below low water, the width at the foundations being 23 feet. The first five courses consisted of Portland cement concrete blocks, 3 feet thick, with a facing of granite headers of the same thickness, each course having a set-off of 1 foot on the face. The rest of the wall was built of Mannez stone, set in courses, in Medina cement, with a batter on the face of 6 inches in a foot. The wall was increased 9 feet in width at the back at the level of low water. The harbour wall was founded 9 feet below low water, the width at the bottom being 14 feet. The four first courses were composed of Portland cement concrete blocks, the two upper courses only being faced with granite.[1] The rest of the wall was built of Mannez stone, set part in cement and part in mortar, the face of the wall having a batter of 4 inches in the foot throughout.

The back of each wall was carried up vertically. The space between the walls was 21 feet in width, and was filled with loose rubble to a distance of 700 feet from the shore, beyond which point concrete filling was substituted, commencing at the level of low water.

The promenade wall was built of Mannez stone set in mortar, with a batter on the sea side gradually curving from that of the face of the sea wall to the vertical; the inner face was built vertical. Arched vaults, reaching 7 feet into the wall, were constructed, on the harbour side, at regular intervals (Plate 5, Figs. 1 and 3). The promenade and quay levels were paved with granite pitching, and coped with granite, and a line of rails was laid down on each level (Plate 5, Fig. 2), the lower one being intended to facilitate the landing or embarking of troops, and the upper one for conveying stone to make up the fore-shore near the face of the sea wall wherever required. Stone mooring posts were placed at intervals along the quay level, and iron ladders and mooring chains in the face of the harbour wall (Plate 5, Fig. 3). The quay level is about 6 feet above high water, and 25 feet wide; the promenade level is about 14 feet higher, and 14 feet wide; there are flights of steps, about 535 feet apart, leading from one level to the other.

The breakwater was proceeded with in accordance with the

[1] Portland cement blocks were substituted beyond 3,400 feet from the shore.

design just described, to a distance of 2,700 feet from the shore, which length had been attained in the year 1856. At that date, in consequence of the proposed extension of the harbour, as desired by the Board of Admiralty, the design was reconsidered by the engineers-in-chief, Messrs. Walker, Burges and Cooper, and certain modifications were introduced in 1860; no advance having been made with the superstructure during the three previous years. The breakwater was narrowed, by reducing the width of the quay from 25 feet to 20 feet; a flight of steps being introduced on the face of the harbour wall at the point of change, and the line of rails on the lower level being stopped near this point. The batter also of the sea face was gradually altered from 6 inches in a foot to 4 inches; solid rubble hearting set in cement was substituted for the concrete hearting, which was found liable to be damaged by storms; and the foundations of the harbour wall were commenced at the same level as the sea wall, viz., 12 feet below low water, or 3 feet lower than previously (Plate 4, Fig. 3). The rest of the breakwater was constructed in accordance with this design up to the commencement of the head, which point was reached in 1863.

The extension of the breakwater necessitated an alteration in its direction, to prevent it approaching too close to the rocks on the other side of the bay, and thus unduly narrowing the harbour (Plate 2). It had been constructed in a straight line from the commencement to 2,900 feet from the shore; it was then curved seawards for a distance of 520 feet, and from thence it was carried in a straight line in a north-easterly direction to the end.

The head was built in 1864 (Plate 4, Fig. 4). To give additional security to this exposed portion of the work, the foundations of the superstructure, for the last 66 feet in length, were carried down to a lower level; 22 lineal feet being founded 18 feet below low water; 2 feet at 21 feet below low water, and the outer 42 feet at a depth of 24 feet below low water; and these foundations were carried at the same level across the whole width of the breakwater. The facing consists, on both sides and at the end, of nine courses of granite headers, 3 feet thick; the backing for the first 30 feet in height being composed of ten courses of concrete blocks: the four upper courses of granite were joggled and dowelled together. The upper portion of the structure was built of Mannez stone in cement, carried up to the promenade level; the seven lowest courses of Mannez face stones being dowelled. Twelve courses of the corner quoins were further secured by iron bars and diagonal straps, fastened by bolts to the masonry, and

built into the work. The end is square, this form having been adopted in preference to the customary rounded end, both on account of the greater simplicity of the workmanship, and in case it should be desired at a future time to extend the breakwater, as contemplated in two of the schemes. It was originally intended to raise the head, and the outer portion of the promenade wall, to the same level as the portion nearest the shore, and to complete the top level with copings, pitching, and a line of rails, as is the case in the length of 2,900 feet from the shore; but, owing to the stoppage of the works, this was never accomplished, and the outer 1,780 lineal feet of the promenade wall, and the head, remain in an unfinished state, about 10 feet above the quay level. The head presents no remarkable feature; and as it does not lie in the proper course of passing vessels, a light is unnecessary at the end of the breakwater.

The entrance to the harbour is marked, at night, by two leading lights, one on the pier of the old harbour, and the other on the rising ground behind. The upper light is open; the lower is eclipsed, by a long tube in front, from any point not leading to the fair-way into the harbour, thus enabling vessels to avoid the breakwater to the west, and the rocks to the east of the entrance. The lamps are lighted by gas, and have earthenware reflectors, 21 inches in diameter, behind them, and exhibit a red light, through a pane of red plate glass in front of each light.

The general method of carrying out the work was as follows:—

The base of rubble stone was deposited from hopper barges towed out by steam tugs. The first barges used carried about 60 or 70 tons of stone; but subsequently larger barges were employed, two being capable of carrying 100 tons each, while one was able to convey a load of about 140 tons. The base was raised to about 12 feet below low water, of sufficient width at the top to receive the foundations of the superstructure; it was carried forward considerably in advance, so as to allow it about three or four years to consolidate before the superstructure was built. Staging was erected across the site, supported on round piles standing on, and fastened to, flat stones, and buried a few feet in the base. The lower courses were laid on the levelled base, in lengths of about 60 feet, by helmet divers, the blocks of masonry and concrete being lowered from the staging. The space between the sea and the harbour walls, up to low-water level, was then filled with small rubble stone and sand as compactly as possible. The walls and hearting were brought up from low

water, on the length of foundations previously prepared, each spring tide, when the weather permitted, between April and September, and nearly up to quay level. At the termination of each length, a wall, of concrete blocks and masonry, was built across the work, to protect it till the next length of wall could be finished; and at the point of termination of each season's work a strong cross wall, 15 feet thick, was constructed, with large concrete blocks and masonry, to protect the end during the winter months. The foreshores of the breakwater were then raised, so as to cover the lower courses of the superstructure up to low water, by tipping large rubble stones over the walls. The promenade wall was proceeded with during the winter months, when no other work could be performed, except depositing the base and preparing materials for the next season's work. The copings, pitching, and lines of rails on the quay and promenade levels, were left till the last, so as to be laid when the subsidence of the walls had ceased. The greatest amount of stone deposited in the base in one year was 608,000 tons; and the greatest length of superstructure completed in one season was 562 lineal feet.[1]

Some rocks which rose to within 5 fathoms of low water, in the space required for the harbour, were removed by blasting. In this manner 37,000 tons of rock were displaced; and the *débris*, where lying in less than 5 fathoms' depth of water, were taken up by means of divers, and deposited on the base and foreshores of the breakwater.

Messrs. McClean and Stileman were appointed chief engineers of the harbour in February 1864, on the resignation of Mr. Burges, shortly after the death of Mr. Walker.

The Harbour Works were transferred, at the end of March 1866, from the Admiralty to the Board of Trade.

Maintenance of the Breakwater.

The breakwater was almost completed, with the exception of the copings and pitching, by the close of 1864. It had previously been injured several times by storms, but in four instances the damage had occurred at the unfinished extremity, which was the most exposed and weakest point of the structure, and these accidents might reasonably be regarded as incidental to unfinished work. In five instances, however, the sea had disturbed portions

[1] *Vide* Appendix, p. 78.

of the finished work; but, up to the period now referred to, the work was only injured, with one exception, at places, near 600 feet and 1,300 feet from the shore, where the superstructure rested partly on rock and partly on the rubble base, entailing unequal settlement, and inevitable opening of the joints of the masonry. The solitary instance where the failure could not be attributed to these causes was at 4,200 feet from the shore, and there the sea made a small breach through the sea wall in November 1863, which was repaired in the same month.

The year 1864 passed without any damage to the walls, though the unfinished quay level did suffer some injury on one or two subsequent occasions. The head having been securely built, there was no exposed unfinished end as in previous years.

On the 13th of January, 1865, a violent gale commenced from the west, and the storm continued, without intermission, for two days. On the 14th, when the storm was at its height, it being also the time of spring tides, the sea forced a way in two places through the breakwater; one opening, 130 feet long, being about 3,900 feet from the shore; and the other, 50 feet long, close to the commencement of the head, both extending from the top to about 9 feet or 10 feet below low water, thus dividing the breakwater into three parts. A breach was also made in the sea wall of the breakwater at 4,370 feet from the shore, and somewhat damaged the finished work at two or three other places. These breaches, which were slightly enlarged during the remainder of the winter, were all repaired in the following summer.

On the 11th of January, 1866, during the violent storm in which the 'London' foundered in the Bay of Biscay, a breach was made in the sea wall at 4,470 feet from the shore. This increased in the next month, and penetrated the harbour wall, the promenade wall, hanging over the gap, alone joining the inner and the outer portions of the breakwater above low water. This was the only damage that occurred during 1866, and it was repaired in the spring of the same year. A small breach in February 1867 was repaired a fortnight after, and, with this trifling exception, the superstructure remained intact during the whole of the year.

During a storm on the 22nd of January, 1868, the breakwater was again damaged by the sea in several places. The worst injury was at 4,000 feet from the shore, where a breach, 60 feet in length, was made through the wall from the top to the level of low water. The head also, which had been slightly damaged in the great storm of 1865, was again disturbed, a few face

stones having been partially displaced some feet below low-water level. These damages were all repaired in the following summer. Before the close of the year the storms of winter again attacked the breakwater, and made a breach through the sea wall at 4,180 feet from the shore on the 28th of December, 1868, somewhat damaging, at the same time, a spot at 600 feet from the shore. These breaches were increased during February and March in the next year, and fresh ones were made in six other places; all, however, were repaired in the summer of 1869, but a violent storm occurring early in the autumn the repairs were disturbed in two places, which were, however, made good before the winter came on.

The year 1870 commenced with stormy weather, and on the 8th of January the sea again damaged the breakwater in seven places, the worst points being at 3,960 feet and 4,450 feet from the shore, where breaches were made right through the walls. In consequence of these successive misfortunes, Mr., now Sir John, Hawkshaw, Past President Inst. C.E., and Colonel, now Sir A., Clarke, C.B., R.E., Assoc. Inst. C.E., were requested by the Board of Trade to visit Alderney, and to report on the best measures for securing permanently, either the whole or the inner portion of the breakwater. In May 1870 they examined the breakwater, and reported to the effect that it would be necessary to remove the promenade wall, and to deposit a large additional foreshore of rubble stone or concrete blocks on the sea slope, to preserve the breakwater effectually from being periodically injured by the sea. They also recommended that, previous to taking any final measures for protecting the breakwater, the rubble base should be carefully measured, during a limited period, to ascertain whether any changes were produced by the action of the sea, as upon the stability or instability of the mound would depend the accuracy of any estimate of the cost of securing the breakwater against damage for the future.

This last suggestion is the only one yet carried into execution. In July 1870, on the resignation of Messrs. McClean and Stileman, Sir John Hawkshaw was requested to proceed with the proposed investigations, and to superintend, as Engineer-in-Chief, the maintenance of the breakwater during the period necessary for their completion; and the Author was appointed to the post of resident engineer, vacated by Mr. May.

The breaches made in the breakwater at the commencement of 1870 were all repaired during the spring and summer months. These repairs remained undisturbed during the following winter,

with the exception of those at 4,450 feet from the shore, where a breach was again opened in October of the same year. This place appears to be specially exposed to the action of the sea, as breaches occurred there on four previous occasions; whereas, elsewhere, the breakwater has rarely been breached a second time at the same spot.

As all the breaches have presented a great similarity in their commencement and subsequent increase, a description of this one may serve as a type of the rest. High westerly winds prevailed early in October; on the 12th and 13th, a small portion of rubble face work, forming a junction between the repairs and the original work, was displaced. The bad weather continuing without intermission, some face stones were loosened and the cement washed out of the joints by the 22nd. The storm still increasing in vehemence, at the height of spring tides, on the 23rd and 24th, some face stones were removed by the afternoon of the 24th. When morning dawned on the 25th the sea was rushing through an opening in the sea wall, each wave passing over the quay level into the harbour, whilst the promenade wall, uninjured, spanned the gap. At that advanced season there was no prospect of fine enough weather to enable the breach to be repaired before winter, and it remained open until the summer of 1871. Repairs to the hearting, to prevent enlargement at the sides and to preserve the harbour wall, had been made in the interim after every storm. The former breaches had been repaired with masonry set in Medina cement similarly to the original structure; but, as this point appeared to be peculiarly exposed to the action of the sea, Portland cement was employed. Also, as the sixth course of masonry from the bottom had subsided a little below low-water level, another course of granite headers was provided, in addition to the supply necessary for replacing the fifth course which had been washed away. Portland cement concrete was used for raising the damaged uneven backing, and for filling the hollows up to low-water level. Above low water the face work was set in 'neat' cement. The backing, composed of rubble masonry and concrete blocks, was set in Portland cement mortar, in the proportion of three parts of sand to one part of cement, except towards the close of each tide's work when equal proportions were used. These repairs withstood the storms of the winter of 1871–1872; and the only injury incurred by the breakwater during that winter was the withdrawal of two face stones at 615 feet from the shore, which were replaced by rubble work in cement.

This brings the history of the maintenance of the breakwater down to the period of July 1872, when Parliament decided to vote no further sums for its repair.

The total cost of the works of construction and maintenance, extending over a period of twenty-five years, amounts to £1,274,200; and of this sum £57,200 were expended in repairs of damages, caused by the sea, to finished and unfinished work.[1]

All works of maintenance were abandoned during the remainder of 1872 and the first half of 1873. In the winter of 1872-3 the breakwater was again damaged by the sea in several places. Face stones were drawn out from the sea wall in four places, due chiefly, in all probability, to the lowering of the foreshore; and a breach was made through the superstructure at about 4,480 feet from the shore. The Government, after long consideration, have decided to resume the work of maintenance, and some of the smaller damages have been repaired during the autumn of this year (1873).

The Superstructure.

The causes of the failures of the superstructure are not now hard to perceive; but, prior to the experience gained from the results of building a breakwater extending into the unprecedented depth of 130 feet of water, it would have been difficult to foresee them. With the exception of places, previously referred to, where unequal settlement necessarily took place, and where the foreshore is rocky and uneven, no damage has occurred to the finished breakwater walls within 3,400 feet from the shore, at which point the depth of the original bottom is 90 feet below low-water level. On comparison with other breakwaters, it appears that at this point the depth in which the Alderney breakwater is built exceeds the extreme depth at Portland by 30 feet; at Holyhead by 34 feet; at Dover by 43 feet; and at Plymouth and Cherbourg by 48 feet. The depth of water, however, increases to the Head (Plate 2), where it reaches the maximum of 130 feet below low water, being three times the extreme depth either at Cherbourg or at Plymouth. One principal cause therefore of the difficulty of the work of maintenance is the excessive depth in which the outer portion of the breakwater is built. To this has to be added the increased force of the sea, owing to the depth and rapid tides, and the exposure to the Atlantic, so that the effects produced are not wonderful. Another cause, arising out of the great depth of water, is

[1] *Vide* Appendix, p. 79.

the subsidence that took place in the immense mass of stone deposited to form the base, when the weight of the superstructure came upon it, the settlement of the superstructure on the mound amounting to about one-twentieth of the height of the mound, notwithstanding the precaution that was taken of leaving the mass for some time to consolidate previous to building upon it. The head, for instance, which was founded 24 feet below low-water level, has settled at least 6 feet in the mound. The subsidence, moreover, was not uniform. Each length having to be rapidly raised above high-water level to preserve it from the sea, there was a small crack at the junction of every fortnight's work. Again, at the junction of the work of two successive seasons, there was a much larger opening; this latter fault was indeed partially remedied by taking down the masonry, for a short distance on each side of the junction of the new with the old work, from the top to low water, and rebuilding it, but the opening could not be closed lower down; hence ensued numerous weak points where breaches usually commenced. In addition to the unequal longitudinal subsidence, unequal transverse subsidence took place, owing to the difference in level of the foundations. Cracks and openings consequently were formed in the interior; and, the solid upper masonry in many places not following regularly the settlement of the lower unconnected courses, horizontal fissures appeared at the joints. Thus air chambers were formed in the interior of the superstructure; and the sea, acting through the open joints in the face, compressed the air in these cavities during storms, which result greatly aided in producing breaches. Amongst the causes conducing to damage must be included the recoil of the waves from the face of the high sea wall, increasing the disturbance of the sea, and helping, by the weight of falling water, to loosen face stones, a result which is also contributed to by the constant dashing of the large stones, forming the foreshore, against the sea wall during a storm.

It is probable that a superstructure with the foundations lower and carried level across, without any structure above the quay level, and with hardly any batter on the sea face, would have resisted the sea more effectually.

In 1860, however, evidence was wanting of the insufficiency of the design, which was at that time amended in two important respects; namely, by the diminution of the batter which threw more weight on the lower face stones, and by the substitution of hearting set in cement for a concreted hearting. Any addition to the diving courses would have considerably increased the expense;

and, the estimates having been framed for a small harbour, in comparatively shallow water, and without a knowledge of the exposed nature of the situation, it is probable that considerations of economy necessarily precluded the idea of any considerable modification of the structure, which in the first instance had not been designed with a view to the position to which it was subsequently extended.

Base and Foreshores.

The quantity of stone deposited in the base and foreshores of the breakwater by the close of 1864 amounted to about four million tons. Since that period, up to the termination of the works of maintenance, the depositing of foreshore was regularly continued; at first to make up the slopes to the required levels, and afterwards to renew the foreshore where removed from the face of the walls by the sea. The amount deposited during the seven years of maintenance was 332,000 tons; the average annual deposit for the first five years being 57,000 tons, while only 48,000 tons were deposited in the last two years. Since September 1871 no stone has been deposited on the foreshores.[1] It had been intended to make the mound of such a form on each side of the superstructure as should remain undisturbed by the sea, rising at the face of the wall on the sea side to the level of low water, and on the harbour side to 6 feet below low water. The natural slopes on the sea side were assumed to be an inclination of 5 to 1 from the wall to 15 feet below low water, changing at that depth to an inclination of $1\frac{1}{2}$ to 1 carried down to the bottom; and the slope on the harbour side $1\frac{1}{4}$ to 1, with a short length of a gentler slope from the top to 9 feet below low water. The base and foreshores were deposited in accordance with these slopes; but it appears, from soundings taken by the Author, that the mound tends to assume a form with slopes somewhat different to those originally laid down (Plate 3). The upper slope on the sea side approaches to an inclination of 7 to 1 instead of 5 to 1, and, where the depth of water is considerable, the change of slope takes place about 20 feet below low water, not 15 feet, as formerly supposed, a short curved slope connecting the

[1] It was found that one ton of the native Mannez stone occupied a space of 20 cubic feet in the mound. As about $13\frac{1}{2}$ cubic feet of Mannez stone weigh one ton, it appears that two-thirds of the bulk of the mound is composed of stone, and one-third of interstices.

two different inclinations. In comparatively shallow water the change of slope takes place in nearly the assumed depth, but the lower slope is flatter. It has, moreover, been found impossible, even with the amount of foreshore annually deposited, to maintain the level of the mound, close to the sea wall, at the level of low water. The effect of the action of the sea, in a single winter, on a heap of 760 tons of large stones, deposited in the summer of 1871, is shown on Plate 3, Fig. 2. From the results of a series of soundings taken by the Author in the years 1870, 1871, and 1872, it appears that a deposit of 32,000 tons of stone in two years is inadequate to maintain the top of the sea slope at $4\frac{1}{2}$ feet below low water. A much larger annual deposit of foreshore would consequently be required to maintain the mound at the top at low-water level, as the disturbing action of the sea varies directly as the level of the mound. The observations of the mound also demonstrate, that it is liable to disturbance by the sea as far as 80 or 90 feet from the wall, on the sea side, and to a depth of 20 feet below low water, but that, beyond these limits, all action of the sea ceases. These limits apply to the outer portion of the breakwater; the limit of depth varies with the depth of water in which the mound is situated, but the limit of distance remains approximately constant throughout the whole length of the breakwater. These limits are greater than were anticipated, and there is no doubt that this extended distance of disturbing action is owing to the recoil of the waves from the sea wall, each wave in a storm rising to a great height above the breakwater, then falling and rushing down the slope of the mound, and opposing an almost irresistible force to everything in its course, till it rebounds some height into the air on meeting the next wave, about 70 feet or 80 feet from the breakwater.

The difference in the force of the sea in different localities, positions, and depths, is probably far greater than is generally imagined. The force would be difficult to compute with accuracy; but its estimation is of the greatest importance in designing structures in the sea; and a comparison between the breakwaters at Alderney and at St. Catherine's Bay, Jersey, will best illustrate this.

The original designs for the breakwaters at Alderney and at St. Catherine's were almost identical. Both were to be carried into about the same depth of water, and both sites were unsheltered by any projecting headland. The differences, as regards the tide and situation with respect to the adjacent coast, were rather in

favour of the Alderney breakwater; the rise of tide at Jersey being double the rise at Alderney, and the breakwater at St. Catherine's stretching more directly out to sea. Both were executed by the same contractors, under the direction of the same engineers, and they are only about 30 miles apart. The history, however, of their construction and maintenance presents a remarkable contrast. The harbour at St. Catherine's was designed to be sheltered by two breakwaters, but the northern one only, commencing at Verclut Point, was completed; the other breakwater, on the opposite side of St. Catherine's Bay, was stopped soon after its commencement, as the Admiralty decided that the harbour was not required, and should be abandoned. The northern breakwater was commenced in 1847 and was completed in 1856, according to the original design. A section of it is given on Plate 6. It is rather more than 2,000 feet in length.

Since its completion no foreshore has been deposited; and, from soundings taken by the Author, in 1871, round the head, it appeared that the alterations in the mound of rubble stone, during a period of fifteen years, were very slight, notwithstanding the great velocity of the tidal current at the head. The only damage of any importance that occurred during these years happened in 1859, when some cracks appeared, and some stones were broken in the masonry of the head, owing to the unequal settlement of the superstructure on the rubble base. These damages were repaired at a cost of about £700; and the Author believes that, from first to last, the cost of maintenance has been under £1,000. At Alderney, on the contrary, the original design had to be modified considerably within the first two years, and the foreshore has been with difficulty maintained by constant deposits of stone.

The only possible explanation of so great a divergence in results is to be found in the difference of position and exposure (Plate 2). Omitting for the present, from the comparison, the outer portion of the Alderney breakwater—where the question of depth would have to be considered—the sea face is exposed, more or less, to winds blowing from any point between south-west and north-west. The meteorological records, kept daily by the resident engineers, show that storms at Alderney present a remarkable similarity in their course. A southerly wind, with a falling barometer, indicates a coming storm. The wind gradually veers round to south-west, west-south-west, and west, the barometer continuing to fall and the force of the wind to augment. When the wind passes to the north of west the barometer generally begins to rise, but the wind continues to increase in violence, veering gradually

to north-west, after which, if it veers further round, the storm abates. If, however, as is not unfrequently the case in the winter months, one gale follows close upon another, the wind backs again to south-west; the barometer falls rapidly, and the phenomena, just described, invariably recur; till at length, at the close of a succession of gales, the wind veers round to the east of north and subsides. The most vehement winds are consequently just those to which the Alderney breakwater lies exposed, and the line of exposure is the Atlantic Ocean.

St. Catherine's breakwater, on the contrary, is situated on the east coast of the island of Jersey, and is only exposed to northerly and north-easterly winds; gales from the first quarter being extremely rare, and the line of exposure being merely the width of the English Channel. From the north-east it is somewhat protected by the French coast; and even at Alderney, which is not equally protected, gales from this quarter, though frequent, are much less severe than those from the west.

Had these meteorological facts been known in 1847 the designs would not have been similar for the two breakwaters; and had it been possible to construct the harbour at Alderney at any other point of the island, it would probably not have acquired such an unenviable notoriety.

Whether any structure could be erected in the position of the outer portion of the Alderney breakwater, that would permanently resist the force of the sea, without the necessity of constant maintenance, has been doubted.

The great recoil of the waves from the sea face of the breakwater might have been diminished by the abandonment of the promenade wall, which is only needed to shelter the quay level, and was more useful during the time of construction than at present, as no lighthouse has been erected at the head. Even, during construction, the upper wall was a source of some damage by causing the waves in a storm to rise a great height into the air, a portion, driven towards the harbour by the wind, descending with great force on the quay level, destroying frequently the temporary roads, and sometimes scooping out the hearting. Without, however, the protection it afforded, the number of working hours on the breakwater in rough weather would have been considerably diminished. A reduced batter on the sea face would have thrown the weight of the superstructure more upon the lower face stones, which was greatly needed; the danger of undermining would have been removed by lower foundations, and the evils of transverse subsidence would have been reduced by carrying the

foundations level across. The injuries arising from longitudinal subsidence would still remain to be guarded against, and would probably prove the only formidable source of danger if any similar construction, in an equally exposed situation, and in equally deep water, was ever attempted again.

The Author has ventured to bring forward the subject of Alderney Harbour, in the hope that the results of building a breakwater in such an exposed situation, and in such an unparalleled depth of water, may not be uninteresting; affording, as it does, experience of the peculiar perils to which such a structure is liable, and of the effects of the sea upon the rubble base.

In conclusion, the Author desires to acknowledge the great assistance the numerous records made by his predecessors at Alderney have afforded him in compiling the early history of the work; and he ventures to express the opinion that the designs of the past should not be judged by the light of present experience.

The Paper is illustrated by a series of drawings and diagrams, from which Plates 2, 3, 4, 5, 6, and 7, have been compiled.

APPENDIX.

I.—Designs for Harbour. (Plate 7.)

No.	Year.	First Lord of the Admiralty.	Estimate.
			£.
1	1847	Earl of Auckland	620,000
2	1854	Duke of Northumberland .	880,000
3	1855	Sir James Graham . . .	1,300,000
4	1856	Sir Charles Wood	1,800,000
5	1858	Sir John Pakington . . .	2,500,000
6	1859	Duke of Somerset	..

The estimate for design No. 3, viz., 1,300,000*l.*, has always appeared in the Parliamentary Returns since 1855 as the estimated cost of the harbour.

In design No. 4, two eastern breakwaters were proposed, one for sheltering the harbour, and the other, from Chateau à l'Etoc to the Grois Rocks, for diverting the tidal current from the entrance.

In 1859, design No. 5 was limited to the points marked A and B on the plan.

The eastern breakwater, from Chateau à l'Etoc to the point B, was abandoned in 1862.

II.—Amounts of Stone deposited in the Mound, and the Average Lengths of Superstructure built each Year, from 1849 to 1872.

Year.	Length of Superstructure Built.	Rubble Stone Deposited.	Year.	Length of Superstructure Built.	Rubble Stone Deposited.
	Lineal Yards.	Tons.		Lineal Yards.	Tons.
1849	85	75,000	1861	136	246,000
1850	82	144,000	1862	187	112,000
1851	101	71,000	1863	126	52,212
1852	104	116,000	1864	22	68,987
1853	104	130,000	1865	..	56,279
1854	121	124,000	1866	..	63,932
1855	146	273,000	1867	..	68,197
1856	146	326,000	1868	..	57,946
1857	13	548,000	1869	..	38,286
1858	..	608,000	1870	..	22,593
1859	..	525,000	1871	..	25,101
1860	113	412,000	1872	..	..

ALDERNEY HARBOUR.

ALDERNEY HARBOUR.

SECTIONS OF BREAKWATER.

Fig 1

1000 FEET FROM THE SHORE

Fig: 2.

2600 FEET FROM THE SHORE.

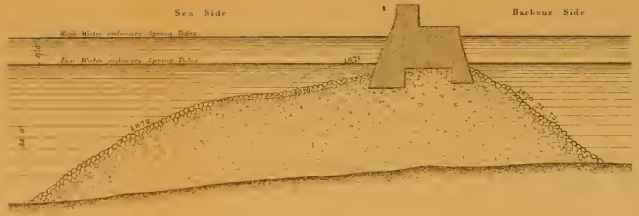


Fig: 3

3600 FEET FROM THE SHORE.

Fig: 4.

4200 FEET FROM THE SHORE.

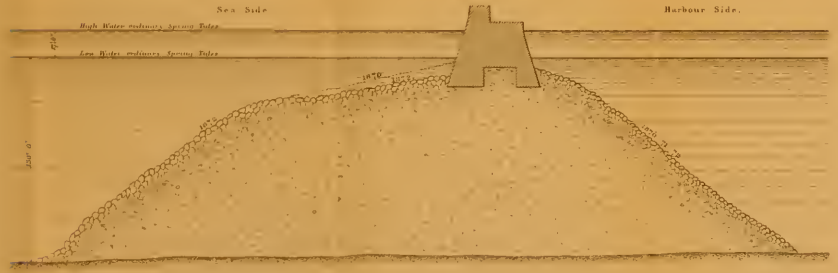
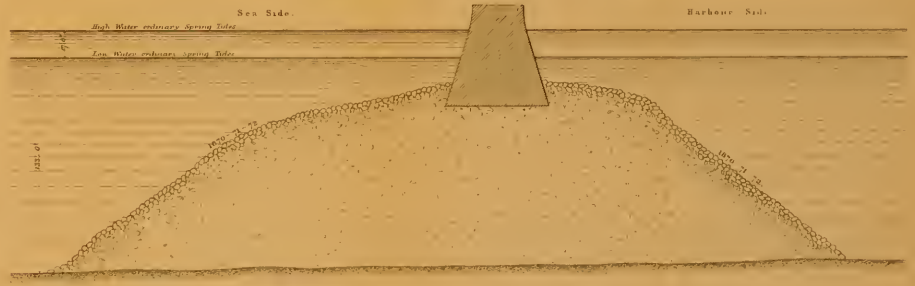


Fig: 5.

HEAD, 4680 FEET FROM THE SHORE.



Scale of Feet

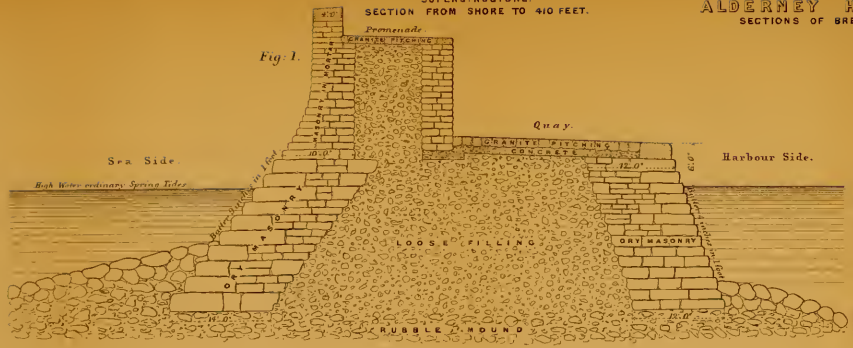
ALDERNEY HARBOUR.

SECTIONS OF BREAKWATER.

PLATE 4.

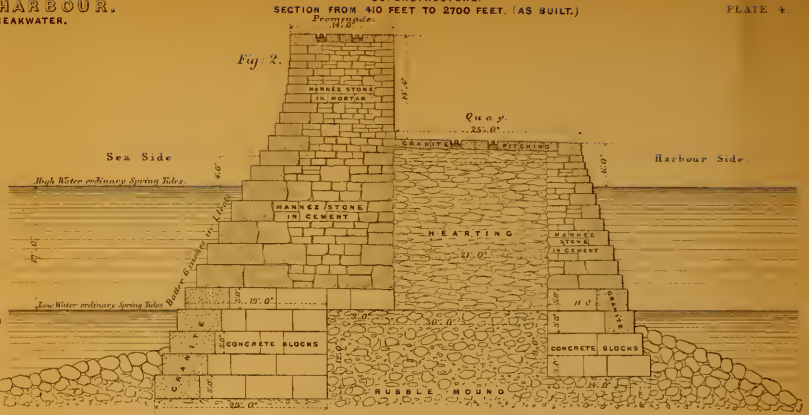
SUPERSTRUCTURE.
SECTION FROM SHORE TO 410 FEET.

Fig: 1.



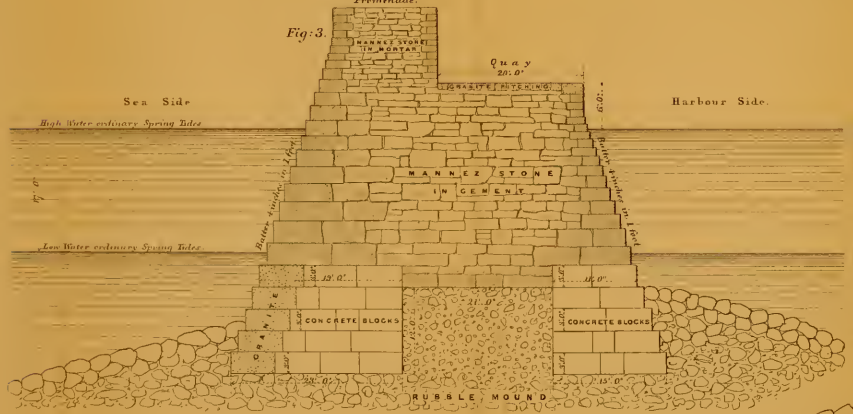
SUPERSTRUCTURE.
SECTION FROM 410 FEET TO 2700 FEET. (AS BUILT.)

Fig: 2.



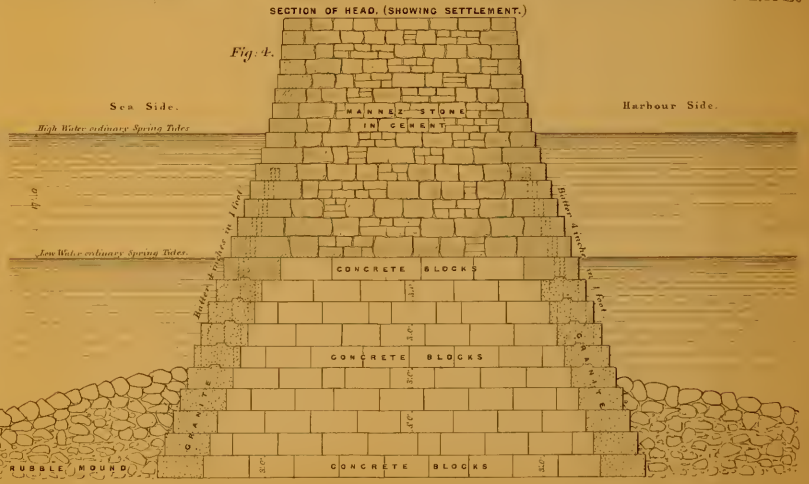
SUPERSTRUCTURE.
SECTION FROM 2700 FEET TO HEAD, (SHOWING SETTLEMENT.)

Fig: 3.



SECTION OF HEAD, (SHOWING SETTLEMENT.)

Fig: 4.



L F VERN N HARCOURT, DEL.

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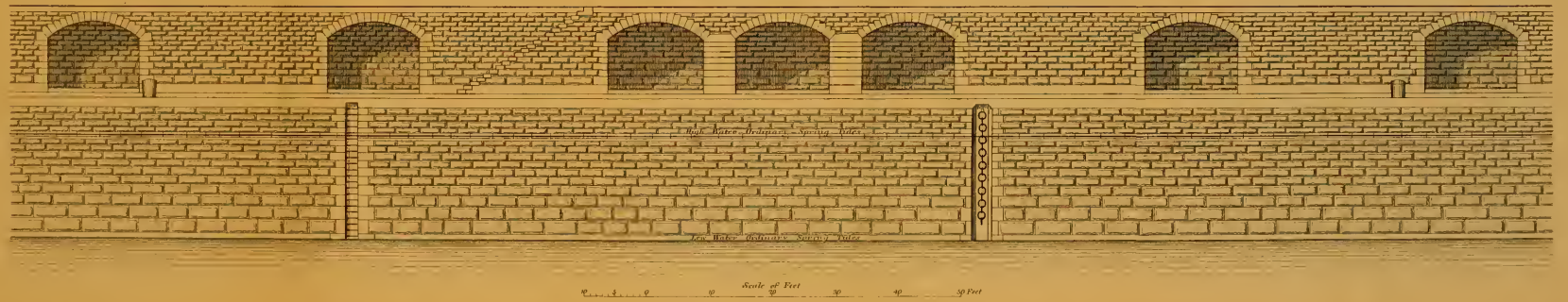
THOS KELL, LITH 40 KING ST COVENT GARDEN.

Fig: 1.
ELEVATION OF HARBOUR SIDE OF SUPERSTRUCTURE.

Fig: 2.
PLAN OF SUPERSTRUCTURE.

Fig: 3.
ELEVATION OF HARBOUR SIDE OF SUPERSTRUCTURE.

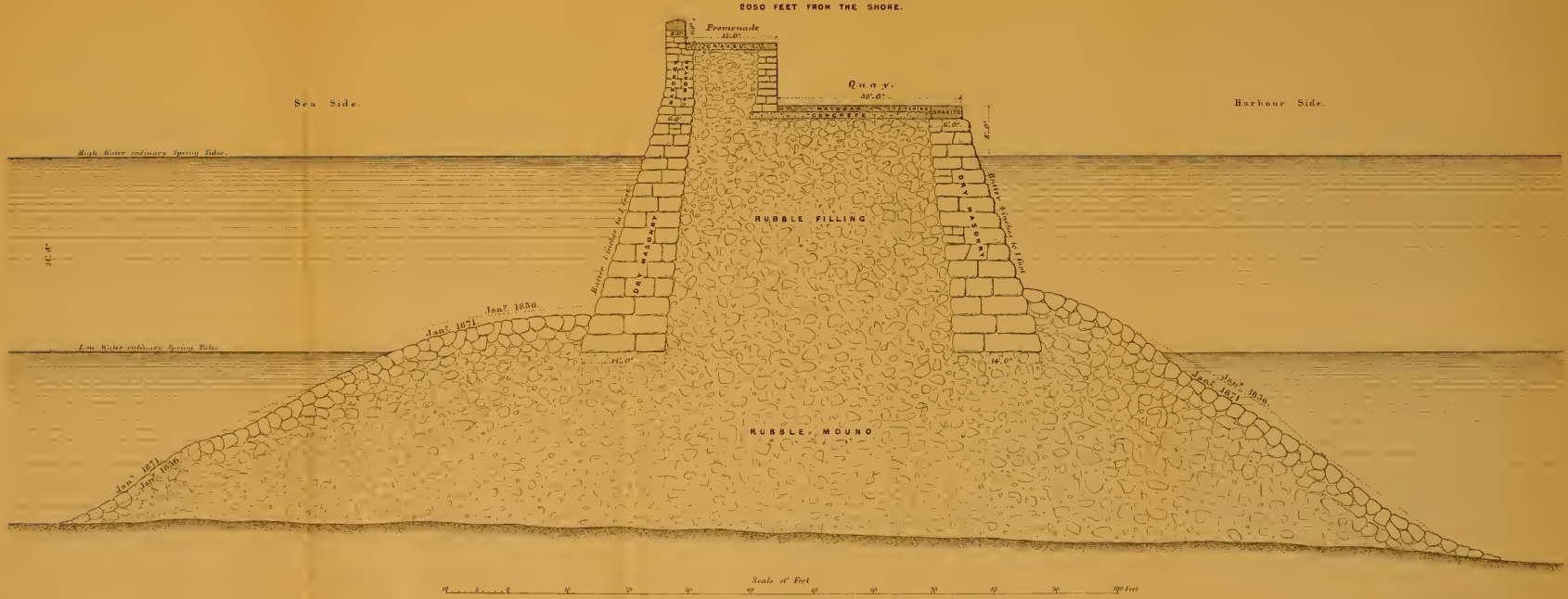


ST CATHERINE'S HARBOUR, JERSEY.

SECTION OF BREAKWATER.

PLATE 6.

To accompany paper on 'ALDERNEY HARBOUR'.



ALDERNEY HARBOUR.

PLAN SHOWING THE VARIOUS DESIGNS FOR THE HARBOUR, FROM 1847 TO 1859.

L. F. VERNON HARCOURT, DEL.

THOS KELL, LITH 40 KING ST COVENT GARDEN

III.—Summary of the Cost of the Works of Construction and Maintenance, from 1847 to 1872.

	£.	£.
Base and Foreshores :—		
Base, 3,000,000 cubic yards, at 3*s.* 3*d.*	487,500	
Large stones deposited on foreshores, 500,000 cubic yards, at 4*s.* 6*d.*	112,500	
		600,000
Superstructure :—		
400 lineal yards, at 310*l.*	124,000	
500 ,, at 345*l.*	172,500	
600 ,, at 355*l.*	213,000	
Head	20,000	
		529,500
Repairs of damages		57,200
Blasting sunken rocks and sundry works		87,500
Total		£1,274,200

IV.—Cost of Repairs of Damages caused by Storms to the Superstructure in each Winter, from 1864 to 1872.

Winter.	Cost of Repairs. £.
1864–5	13,500
1865–6	2,170
1866–7	114
1867–8	5,315
1868–9	10,226
1869–70	11,144
1870–1	1,706
1871–2	50
Total	£44,225

V.—Table giving the Number of Days on which Easterly Winds prevailed, in each Month, for a period of Twenty-two Years. 1850—1871.

——	1850.	1851.	1852.	1853.	1854.	1855.	1856.	1857.	1858.	1859.	1860.	1861.	1862.	1863.	1864.	1865.	1866.	1867.	1868.	1869.	1870.	1871.	Totals.	Averages.
January .	19	4	..	9	5	20	15	13	12	9	9	16	13	8	15	9	6	14	11	10	15	14	246	11
February .	4	15	10	22	11	21	14	10	21	4	17	12	17	13	20	10	6	6	..	3	11	10	257	12
March . .	19	6	27	19	13	14	27	11	16	4	7	3	17	11	14	16	14	20	5	19	17	19	318	14
April . .	10	17	25	5	21	17	14	14	18	8	21	24	14	11	17	24	15	3	14	10	12	9	323	15
May . .	19	12	19	18	8	14	14	14	10	24	10	20	9	15	16	11	16	17	12	13	16	21	328	15
June . .	14	8	3	6	8	10	9	9	9	13	4	9	5	7	3	18	11	15	10	14	10	16	211	10
July . .	8	7	17	2	10	6	7	7	10	12	13	3	4	18	11	1	12	10	16	14	15	5	208	9
August .	3	10	5	15	9	10	11	11	10	10	..	3	17	5	12	7	2	10	8	19	13	17	207	9
September	16	21	16	11	18	20	10	10	13	5	12	6	16	2	5	19	4	10	17	7	13	18	269	12
October .	9	10	15	9	11	5	16	16	14	11	11	22	9	14	22	12	22	10	7	17	10	13	285	13
November .	5	16	8	17	13	21	18	18	24	17	20	9	23	9	12	11	7	23	20	8	11	22	332	15
December .	10	14	4	27	3	15	9	9	11	14	17	17	6	4	15	15	4	12	6	15	23	10	260	12
Totals .	136	140	149	160	130	173	164	142	168	131	141	144	150	117	162	153	119	150	126	149	166	174	3,244	147

VI.—Table giving the Number of Days on which Westerly Winds prevailed, in each Month, for a period of Twenty-two Years. 1850—1871.

——	1850.	1851.	1852.	1853.	1854.	1855.	1856.	1857.	1858.	1859.	1860.	1861.	1862.	1863.	1864.	1865.	1866.	1867.	1868.	1869.	1870.	1871.	Totals.	Averages.
January .	12	27	31	22	26	11	16	18	19	22	22	15	18	23	16	22	25	17	20	21	16	17	436	20
February .	24	13	19	6	17	7	15	18	7	24	12	16	11	15	9	18	22	22	29	25	17	18	364	17
March .	12	25	4	12	18	17	4	20	15	27	24	28	14	20	17	15	17	11	26	12	14	12	364	17
April . .	20	13	5	25	9	13	16	16	12	22	9	6	16	19	13	6	15	27	16	20	18	21	337	15
May . .	12	19	12	13	23	17	17	17	21	7	21	11	22	16	15	20	15	14	19	18	15	10	354	16
June . .	16	22	27	24	22	20	21	21	21	17	26	21	25	23	27	12	19	15	20	16	20	14	449	20
July . .	23	24	14	29	21	25	24	24	21	19	18	28	27	13	20	30	19	21	15	17	16	26	474	21
August .	28	21	26	16	22	21	20	20	21	21	31	28	14	26	19	24	29	21	23	12	18	14	475	22
September.	14	9	14	19	12	10	20	20	17	25	18	24	14	28	25	11	26	20	13	23	17	12	391	18
October .	22	21	16	22	20	26	15	15	17	20	20	9	22	17	9	19	9	21	24	14	21	18	397	18
November.	25	14	22	13	17	9	12	12	6	13	10	21	7	21	18	19	23	7	10	22	19	8	328	15
December .	21	17	27	4	28	16	22	22	20	17	14	14	25	27	16	16	27	19	25	16	8	21	422	19
Totals .	229	225	217	205	235	192	202	223	197	234	225	221	215	248	204	212	246	215	240	216	199	191	4,791	218

Note.—From Tables V. and VI. it appears that in April and November easterly and westerly winds are, on the average, equally prevalent; whereas in June, July, and August, westerly winds are more than twice as prevalent as easterly winds.

VII.—Table giving the Number of Days on which Easterly Gales prevailed, in each Month, for a period of Twenty-two Years. 1850—1871.

——	1850.	1851.	1852.	1853.	1854.	1855.	1856.	1857.	1858.	1859.	1860.	1861.	1862.	1863.	1864.	1865.	1866.	1867.	1868.	1869.	1870.	1871.	Totals.
January . . .	2	..	..	..	2	4	4	4	2	..	1	2	..	1	2	3	2	5	..	..	..	2	36
February . . .	..	1	1	..	..	6	3	..	8	..	7	2	3	..	3	..	2	1	..	..	5	..	42
March	..	..	1	1	1	2	5	2	3	..	..	..	2	1	2	5	3	8	..	5	2	3	46
April	..	..	..	..	1	..	3	..	..	2	2	..	2	..	..	..	3	..	2	..	..	..	15
May	1	..	1	..	..	1	2	1	..	1	..	3	1	2	..	..	3	1	2	5	..	..	24
June	..	..	..	..	..	..	..	..	..	..	1	..	..	1	..	..	..	..	..	..	..	..	2
July	..	..	..	..	..	..	..	..	1	..	..	..	..	..	..	..	..	..	..	..	..	..	1
August . . .	..	3	..	..	..	..	1	..	..	..	..	..	..	..	2	..	..	..	..	..	..	..	6
September . .	..	..	..	..	..	..	..	..	..	2	1	1	4	..	..	..	..	1	3	1	..	3	16
October . . .	..	1	1	..	2	1	..	1	1	1	1	4	..	3	5	1	1	..	1	3	..	..	27
November . . .	1	..	..	..	3	7	1	4	5	1	2	1	2	2	1	3	1	3	4	1	..	..	42
December . . .	..	1	..	5	..	..	..	..	..	3	1	5	..	1	2	..	..	4	..	8	..	2	32
Totals . . .	4	6	4	6	9	21	19	12	20	10	16	18	14	11	17	12	15	23	12	23	7	10	289

Note.—It appears from the above Table that, for places exposed to the east, November, February, and March are the worst months, and June, July, and August, the most favourable months for sea works.

VIII.—Table giving the Number of Days on which Westerly Gales prevailed, in each Month, for a period of Twenty-two Years. 1850—1871.

——	1850.	1851.	1852.	1853.	1854.	1855.	1856.	1857.	1858.	1859.	1860.	1861.	1862.	1863.	1864.	1865.	1866.	1867.	1868.	1869.	1870.	1871.	Totals.
January . . .	1	3	5	2	..	1	2	4	2	2	15	1	4	8	..	9	9	6	10	11	8	4	107
February . . .	1	..	5	1	1	..	2	1	1	5	3	3	..	1	2	7	11	6	8	7	1	2	68
March	..	4	..	..	..	2	..	3	3	8	5	14	2	4	5	7	3	..	9	6	..	1	76
April	2	..	..	1	..	1	..	1	..	3	2	..	..	..	..	..	1	8	3	4	..	6	32
May	..	..	..	..	..	..	1	..	2	..	2	..	1	..	..	..	2	..	..	..	1	..	9
June	..	..	..	..	..	..	..	..	..	..	..	..	4	1	..	..	1	..	..	..	..	..	6
July	..	..	..	..	..	..	1	..	..	..	..	2	..	..	..	..	..	2	..	..	..	1	6
August . . .	..	..	1	2	..	..	.	..	..	3	8	..	2	1	..	..	3	..	2	..	..	..	22
September . .	4	..	..	2	..	..	5	..	..	5	..	6	..	7	..	..	8	..	3	6	2	2	50
October . . .	1	3	4	3	5	2	1	4	3	3	8	1	8	6	2	9	1	4	5	2	10	1	86
November. . .	4	1	2	2	1	..	..	..	1	9	3	11	2	9	11	10	10	1	3	8	..	..	88
December . . .	4	2	4	1	8	5	8	3	7	9	6	4	6	4	2	5	9	4	19	11	...	1	122
Totals . . .	17	13	21	14	15	11	20	16	19	47	52	42	29	41	22	47	58	31	62	55	22	18	672

Note.—It appears from the above Table that, for places exposed to the west, December and January are the worst months, and May, June, and July, the most favourable months for sea works. May is the only month in which, on the average, westerly gales are less frequent than easterly gales.

Mr. Redman thought, although his knowledge of the Alderney harbour only extended back eight years, that many of the sweeping criticisms upon the breakwater had been made without all the conditions surrounding the work having been taken into account. Two names ought to be mentioned in connection with this work, in addition to those referred to by the Author. One was Major Newsome, R.E., a pupil of the chief engineer, who had obtained a commission in the Engineers after the age of twenty-five, and was stationed at Alderney; the other was the late Mr. James Cooper, M. Inst. C.E., who was really and truly the engineer, having prepared the specifications and working drawings, and taken the general supervision of the works, his chief, then of great age, almost entirely relying upon him. Mr. Cooper was a man of the highest honour and professional attainments, and was suddenly removed by death in the very springtide of success. Mr. May, whose talent, energy, and attainments were acknowledged by every civil and military resident in the island, was the resident engineer after the retirement of Mr. Parkes, M. Inst. C.E., the present consulting engineer to the Kurrachee harbour. This breakwater, like all the others on the English coasts, except Plymouth, had grown out from the shore, *pari passu;* and the fact of its being commenced from the shore necessitated the greatest caution in determining the outline to form the harbour. The result had been a defect like that at Holyhead, for the harbour, projected originally for a smaller enclosure, was subsequently diverted from the shore. Had a curve of contrary flexure been adopted, there would have been a considerable addition to the area. The Author had stated that the breakwater was three times the height of any similar work upon the English coast; and from the fact of the section of the St. Catherine's pier, at Jersey, being so similar to that at Alderney, the inference was that the different conditions of the two sites were not understood at the time. But the section of the St. Helier's pier more closely resembled St. Catherine's than the section of St. Catherine's resembled that of Alderney. The Jersey section of breakwater for a tidal harbour upon a stable base was successful. St. Catherine's, upon a lower mound in a less exposed situation, was equally successful. But the section of the Alderney breakwater was unsuccessful, owing, no doubt, to the different degrees of resistance presented by the enormous mass of rubble mound seaward, as compared with its dimensions near the shore. Hence, unequal settlement caused the longitudinal and transverse fissures which had proved to be points of weakness, and ultimately led to the breaches. That the two sites

must have been thoroughly understood at the time was evident from Captain White's Channel directions for those seas, published about the period of the commencement of the works. The peculiarities of the seas were there given. The currents were tremendous, attaining, through the Race of Alderney, a velocity of 7 or 8 miles an hour. The total range of tide at Alderney was 18 feet; at Guernsey 20 feet; at Jersey 32 to 34 feet; at St. Malo 42 feet, rising, at equinoctial spring tides, to 47 feet. At Alderney there was an uninterrupted offing to the west and south-west. Between Alderney and the French coast the distance was 9 miles, and from the cliffs of St. Catherine's the outlines of the well-known cathedral of Coutances, in Normandy, could be plainly seen on a fine day. The depth of water at St. Catherine's was about one fourth that at Alderney, and the point of exposure was partly protected by outlying rocks. Of the various sites along the coast, Dover had an offing, from south-west to south-west by west, of 150 miles, with a mean depth of 120 feet, inclining to 40 feet at low water where the pier was situated. Cherbourg had an offing of 100 miles, with a mean outlying depth of 200 feet, rising to a depth, at the site of the breakwater, of 30 feet. Portland had an offing of 140 miles between south-west and south-south-west, with a mean channel depth of 200 feet, rising to 50 feet at the site of the breakwater. Plymouth had an offing, with the exception of the headlands protecting it, of the whole breadth of the Atlantic between west-south-west and south-west; but taking 100 miles, the edge of the bank next the deep channel soundings, there was a depth of 300 feet, rising to 30 feet at the site of the breakwater at low water. Holyhead had an offing of 100 miles between north-west and north by east, with a mean channel depth of 400 feet, inclining up to 45 feet at low water. Wick, which as regarded exposure was placed in a position somewhat similar to Alderney, had an offing of 600 miles between north and north-east to the Scandinavian coast, with a depth of 900 feet; but taking it at 90 miles at a depth of 300 feet, there was an incline from that up to 35 feet, at low water, at the site of the breakwater. At Alderney there was an uninterrupted offing to the West Indies and to Newfoundland, 3,000 or 4,000 miles, between west and south-west; but taking 100 miles at 300 feet, there was a rise to only half that depth, so that its conditions were very different to any other breakwater. The question as to the possibility of continuing the work was answered in the Paper itself. Various breaches had occurred, but it was a remarkable fact that the pierhead, in the most exposed situation, and on the greatest altitude of rubble mound, had

remained uninjured from the time of its formation. He had no hesitation in expressing his belief that the work might be maintained in a safe and economical manner. He did not advocate the removal of any portion of the work, or any extreme measure. The breakwater at Cherbourg had kept up, for a century, a continued contest with the elements, and had been subjected to a series of breaches and re-formations. There had been similar catastrophes at Plymouth, at various Irish harbours, at the Isle of Man, and in Scotland. Some persons, who resolved all works of that kind into a current money value, spoke of the abandonment of the Channel Islands just as rash men had advocated giving up Gibraltar, or Malta, or the Gold Coast. The public, however, viewed the work at Alderney with admiration, as having been boldly conceived, and carried out in the same spirit.

Mr. John Jackson said, he had been the contractors' agent for the breakwater works at Alderney from the year 1857 to the year 1866. For five years previous to 1857 he had been engaged on the fortifications in the island. The Alderney stone, of which most of the breakwater was built, had been described as sandstone grit, but that term would probably convey an erroneous impression as to its hardness. It was much harder than granite, harder even than the Guernsey granite used in the streets of London. A man could jump two lewis holes in the granite in the same time that it would take him to jump one in the Mannez, or native Alderney stone. One jumper sufficed to bore a hole in the granite, but two were required for the same operation in the Mannez stone. This stone readily spauled with hammers weighing 32 lbs., which the men got very expert in handling, but the blacksmiths had great difficulty in giving the right temper to the steel tools in use. Seventy-four tons of powder were consumed per year in the Mannez quarries. These were distant about 2 miles from the commencement of the breakwater, and had a face 75 feet high. Four locomotives and four hundred wagons were used in bringing the stone down; and both the rough stone for the bank, and the dressed stone for building the walls, were obtained from them. The mode of quarrying was as follows:—Shot holes from 6 feet to 8 feet deep were drilled at the toe of the quarry face, and charged and exploded. When the rock was sufficiently undermined a deep hole was drilled down from the top of the quarry to a shelf or bed, of which there were several, inclined at an angle of from 25° to 45° to the face; this hole was charged with powder, lightly tamped and exploded several times, till a crack was made longitudinally; then into

the crack large grained powder was poured and exploded, bringing down a considerable mass of rock. By this means the stone was not too violently shaken, and good face stones were obtained. He had seen one piece in a mass so brought down 45 feet long, 5 feet wide, and 2 feet 6 inches thick, the thickness probably not varying $\frac{1}{4}$ inch in the whole length; but stones of such dimensions were not often met with. The greatest quantity of material conveyed to the bank in one day was 3,000 tons, and this was tipped over a single road. From the mass of rubble a careful selection was made, first of stones suitable for facings, then of stones fit for backers. These weighed from 3 tons to 15 tons, and were used in the rubble hearting at the back of the sea and harbour walls. Many of the face stones were 9 feet long on the face, 3 feet 3 inches thick, and 15 feet on the bed. The cost of dressing them into shape came to 6*d*. per cubic foot. For many years it was stipulated that every barge load of rubble stone should be supplemented with ten wagon loads of sand and shingle, with the object of filling up the interstices of the bank, but the anticipated result never happened, and the sand made a mound on each side of the toe of the bank. After repeated remonstrances on the subject, Mr. May, the engineer, by a personal examination of the bottom of the bank, ascertained that the facts were as stated, and the deposition of sand was discontinued. Apparently, the water being rarely if ever still, before the sand could settle, the current took it off the line of the bank, the ebb tide sweeping it to seaward of the line of the slopes, and the flood tide into the harbour. The contractors were deeply interested in the subject, for no allowance or measurement was made for any material deposited outside the line of the slopes of the bank. He might mention, to the credit of the captain of the barges, that extremely few loads of stone were not tipped on the line of the slopes, and that, in such a rough sea as they sometimes ventured out in, spoke volumes for the pluck of the bargemen. One laden barge capsized with the crew, but as life-buoys were available, and the life-boat in its place, no one was drowned. To deposit the rubble, the traps of the barges were opened when the vessels were in line with the base of the breakwater, as indicated by the lights or targets erected on the high land.

In building the walls, as no machinery of any kind could remain out during the winter, the works had to be recommenced every year. The first operation was taking down a machine called the "Samson," invented in Alderney. This was like a railway turntable on wheels, with balks of timber 76 feet long, placed

across and over-trussed; one end, which projected past the side of the table farther than the other, was called the jib, and at the other end was the balance weight. A double-purchase crab was fixed in the centre, which worked a chain over a travelling sheave near the end of the jib; and the whole revolved on the under frame. The gauge was 15 feet, just the space left between the travellers or gantries spanning the sea and harbour walls. This machine was capable of lifting a weight of 4 tons in the water at a distance of 30 feet from the outside edge of the turntable. The first operation was to stretch the jib outside the end of the previous season's work, the foreman labourer standing on the outer end; this man held a copper wire, attached to a large cast-iron plumb bob, which, at slack tide, he let down to the place where the first pile or upright of the stage was to stand, and at this spot a helmeted diver excavated a hole in the bank to receive the pile, to the end of which was fastened a stone weighing 15 cwt. When the hole was excavated to the required depth the divers retired, and the pile was lowered by the "Samson" into its place. Four piles were set in a row 30 feet apart, and longitudinal trussed beams 2 feet 4 inches by 1 foot 2 inches were placed from pile to pile, and formed a bay of staging, which consisted of 1,050 cubic feet of timber, and 3 tons 8 cwt. of wrought iron in trussed rods, knees, bolts, straps, &c. The carpenters erected a bay of staging in a week. When the stage had advanced seawards three lengths or bays, six travellers or gantries, each capable of lifting 20 tons, were taken down the wall, an operation performed by the carpenters generally in one day. The gantries spanned the sea and harbour walls, and the space between was occupied by two lines of railway for conveying men and materials, and in this way the whole width of the top of the stage, viz., 70 feet, was occupied.

About the middle of May in every year the first block was lowered by the helmet-divers' gantry to its place. The helmet-divers' stage was suspended by iron rods from the beams of the main stage, and hung about 10 feet below it. To this stage wrought-iron ladders were attached for the convenience of divers descending to their work. Six divers were under water together, four on the sea side, and two on the harbour side; they remained down four hours at a time, when there was a shift, and there were three shifts in the day. The life-line men and pumpers remained on the work all day, but the pumpers were relieved every half hour. The divers' apparatus and the stage were removed every night, so treacherous was the sea, for even in summer it was not safe

to leave anything at the level of the divers' stage; but at the height of the main stage, 10 feet higher, or 20 feet above high water, the sea seldom disturbed anything. The mode of bringing the work up was by taking advantage of the spring tides; thus it was expected of the divers that, in a fortnight, they would bring the diving work up to the level of low water, for a distance seaward of 60 feet, ready for the masons; and during his management of the works, whatever excavation was required for the lowest course, it being a great deal more at some times than at others, or however rough the sea might have been, the divers never failed to prepare a length of 60 feet, but they frequently went down a second time for an extra shift to accomplish this. The average day's work of a diver in the year 1860 was $8\frac{1}{2}$ cubic yards of building, in 1861 it was 11 cubic yards, and in 1862 it was 14 cubic yards. Their work was excavating foundations, receiving the granite face stones for the sea wall, and setting the granite and concrete blocks of the sea and harbour walls. The stones and blocks were speedily lowered by a single chain 45 feet from the top of the stage by the gantry crabs and a rope-break. The latter was a piece of rope, with rope yarn twisted round, made fast to the frame of the crab, and then fastened to the pinion shaft of the single and double gear. When the men working the crab had got the block over the place where it was intended to be lowered, the breaksman laid his hands on the rope-break, and slightly moved the rope; and in that way lowered the stone as quickly or as slowly as was wished, without any jerk, having it under complete command. Nowhere else had he seen the rope-break worked with such skill as at Alderney. The operation was performed much more expeditiously than it would have been had double-sheaved blocks been used. The chains employed were of the best charcoal iron, $\frac{7}{18}$ of an inch thick, and they were only used for two seasons. He once found a man unconcernedly smoking his pipe, and allowing a large stone to lower itself, having tied a thin piece of string to the break; this was in such order that the slight tension of the twine was sufficient to hold it. These men were of good nerve and clear-headed; any mistake on their parts would have brought death to the divers below; but he was proud to say that during the many years the operations were in progress at Alderney not a diver lost his life.

The divers' work being ready for the masons, to the level of low water of spring tides, two days before full or new moon, the resident engineer gave orders to commence setting the face stones in cement, if, in his opinion, the tide fell low enough, otherwise he could stop the works. The masonry of the breakwater on the sea

face was of granite and native Alderney stone; on the harbour side it was of native stone, and the space between was filled in with backers and small rubble. The backers were as large as the machinery would lift, and were set in Medina cement and sand, in the proportion of 1 part of cement to 2 parts of sand. Sand suitable for building occurred in abundance in the island; and he had known one man fill 25 cubic yards a day into wagons. All the sand used was procured from a single bay about $\frac{1}{2}$ mile from the works. The cement was brought from the Medina river in the Isle of Wight, and no better could be had for the purpose, for very often the masonry, ten minutes after it was built, was covered with water. No large stock of cement was laid in, as its quick setting qualities were impaired by time. The masons endeavoured to keep the work done at each tide as long as possible out of the water, and to get a course closed up in one operation. When the masonry had been brought up three courses the tide was considered to be mastered. The helmet divers had two gantries appropriated to their work, and the masons had four. The masons came out at noon and at midnight, and it was always low water at that time; therefore nearly half of the wall above low water was built in the night. The average day's work for each mason was $6\frac{1}{5}$ cubic yards, and no piece-work was permitted in the actual building of the breakwater.

The storms that occurred at Alderney during the winter were very severe. He had seen the sea strike the wall and mount up into the air 200 feet. The concurrence of several circumstances, however, were required to produce a damaging storm; the storm must happen at the top of spring tides, and the wind for several days must have blown from the south, and gradually, as the gale increased, have veered towards the north-west. The heaviest seas and the greatest rush of water over the wall occurred an hour after high water, when the ebb tide beginning to make down in-shore met the unexpended flood just opposite the outer end of the breakwater. At this time stones on the foreshore were hurled against the face of the wall, or shot high into the air; and stones of 9 tons' weight were lifted from the foreshore over the top of the wall, a height from where they originally rested of 45 feet. On one occasion, during an unusually severe storm, a piece 9 inches long was broken off, by a stone hurled into the air, from the double-headed rail of the permanent way, which weighed 65 lbs. to the yard, the broken ends of the rail being left in perfect line, and not bent downwards. During gales the dull thud of the heavy waves striking the breakwater was heard at a long distance; and once so terrified were

the crews of three ships laying under its shelter, that the captains of two of them actually slipped their anchors, and ran the vessels aground in the bay, though there was not the least necessity, as they were in a perfectly safe position; while the captain of the third hoisted signals for assistance to take the crew on shore, but such was the force of the wind that it was impossible to reach the vessel even with the steam tug. In the summer ground seas were sometimes felt. These were very dangerous, and some of the men lost their lives through them. They came on with scarcely any warning, and, strange to say, on the hottest and calmest days, the sea being otherwise like a mirror; but they struck terror into the stoutest hearts connected with the work. At their approach divers, carpenters, and masons sought the nearest shelter, the divers being at once ordered up, and their stage and apparatus hastily hurried away. In a few minutes a tremendous body of water would be flung against the wall, and there being no wind, the wave would mount up a vast height into the air. This commotion would last an hour, perhaps, or less, when the sea would as suddenly subside as it had risen. Many thousands of yards of the work under water were shifted by the ground seas, and the men were often kept prisoners in the arches of the promenade wall during the time they lasted. He had been caught in one of these arches when, in front, a wall of water several yards thick had fallen; quite enough, had it happened on the Dover pier, when the express train was waiting there, to have washed carriages, passengers, and engine into the sea. The phenomenon was particularly fearful at night; and at one time a large net was stretched along the row of uprights at the commencement of the season's staging to prevent the men being washed into the harbour. In his opinion these seas were not so heavy during the last few years of the construction of the breakwater. The diving work was always ended in August, and the building up to the quay level in September, while the promenade was generally finished before Christmas. Previous to his taking charge of the works, no greater length of wall was built in one season than 300 lineal feet, but this was gradually increased, till a length of 600 feet, including formation, was built per year.

Considering the exposure of the wall, built as it was on a bank of such height, and that the cost of repair would amount to not quite 4 per cent. on the total sum expended, he must confess his surprise that its maintenance should have been the subject of deliberation by a committee of the House of Lords. The late Duke of Wellington had directed attention to the strategical importance

of the island of Alderney, and Sir Robert Peel coincided with and endorsed that opinion. As a resident on the island for fourteen years, he thoroughly agreed in that view; and being well acquainted with the neighbouring coast of France, he could confidently assert that the position of Alderney, if properly taken advantage of, was of the greatest importance to England. He had seen, while sailing between Alderney and the Isle of Wight, Portland, Alderney, and the coast of France in view at the same time. Portland was 50 miles, the coast of France was 9 miles, and Cherbourg was 25 miles from Alderney; therefore, with a small fleet in Alderney and Portland the Channel would be completely blockaded. Cherbourg, the finest artificial harbour in the world, was capable of sheltering under its breakwater any three of the navies of the great powers. Cherbourg being to the north-east of Alderney, and Brest well to the south, made the position of Alderney, in conjunction with Portland, such that, in time of war, a fleet stationed there would at once protect and guard the Channel, and hold in check the fleets lying in Cherbourg and Brest. The value of this fact to England could hardly be over estimated, and it was only by a visit to the places mentioned that it could be appreciated. On these grounds, if for no other reason, Alderney Harbour should not only be kept in repair, but completed.

Sir John Coode observed that one peculiarity of the harbour of Alderney, which amounted, in his opinion, to a material drawback, was its narrowness as compared with its length; but that was a circumstance over which the engineer had no control. From the breakwater itself to the 3 or 3½-fathom line (the least depth available for the anchorage of any vessel of tolerable size in the navy) was only about 400 yards, and would therefore not admit of two lines of vessels abreast. The commander of one of Her Majesty's frigates, who was there some years ago in attendance upon the Queen, had told him that for two nights and a day he could not venture to take off his clothes. When the wind was in one direction he was afraid the vessel would run against the breakwater, and when it was in the other that the vessel would run on the rocks. It was also worthy of note, that the mouth of the harbour was rather wider than the harbour itself; consequently when the wind was from the north-east, the sea coming into the harbour made matters very uncomfortable. It was open to the north-east as far as Beachy Head, a distance of about 120 miles. About ten years ago he was requested by the Admiralty to visit Alderney. He was to have gone in the 'Dasher,' but as that vessel was in the hands of the dockyard authorities, he engaged a steamer,

110 or 120 feet long, for the purpose. On reaching Alderney the steamer brought up at the Queen's Buoy, supposed to be one of the best berths in the harbour. The next morning the captain came ashore and said, "I hope you are not going to stay here long." "What is the matter?" he asked. The captain replied, "My crew is in a state of mutiny; the steamer is pitching bows under, and I do not know what to do." His advice was that if it was fit to go outside, and the men would not stay, they had better go to Cherbourg. He mentioned this to show the necessity for something being done in the way of protection from the north-east. If Government was about to spend more money on the work, with the view of converting the place into a harbour, they should make up their minds to construct the eastern arm. There was no doubt that the breakwater at Alderney was exposed to a tremendous sea, but this was not wholly due to the exposure of the site. No one could deny that the exposure was great; but the very heavy sea against the pier was mainly due to the peculiar configuration of the bank, and to the profile of the work itself. A similar thing took place at the Edystone lighthouse, where, with a similar profile, at the close of a gale, the sea would often break over the top of the lantern. The settlement to which the work had been subject, and the breaches that had been described, were, he thought, in a measure due to the want of solidity in the bank—to an insufficient amount of small material to fill the interstices. Mr. Jackson had referred to the difficulty of getting in the small material. He did not know whether Alderney differed so much from other places, that it was impossible to insert some barge-loads of sand every day at slack water. If, however, that could not be done at spring tides, then it should be tried at neap tides; and he thought that, with proper arrangements, a larger quantity of small material might have been introduced, and the bank thereby rendered more solid. With regard to the Mannez stone, it was of a quartzose character, very hard, and equal to 13½ cubic feet to the ton, representing a fraction over 20 cubic feet in the bank. From experience elsewhere he found that stone weighing 15 feet to the ton, therefore of less specific gravity, might be got into the bank with a solidity of as much less than 20 feet as the Alderney stone exceeded it. The solidity of the Alderney bank, therefore, was certainly not all that was desirable. It had been said that Cherbourg would shelter three of the finest navies in the world—a statement to which he must take exception. The area of the harbour was no doubt very large, but the portion of it available for ships of war was relatively very small—so small

that, if it were true that Cherbourg would shelter three of the finest navies in the world, Portland would shelter twelve. A large portion of the area at Cherbourg was greatly exposed, and open to a fetch of about 75 miles. The position of Alderney was, undoubtedly, of great importance. He believed it was recommended by the late Duke of Wellington as a check upon Cherbourg. Reference had been made to the fact of Alderney and Portland being in sight at the same time. He remembered on one occasion seeing Alderney from the top of Portland; and he had even, when standing on the Portland breakwater, heard the guns of Cherbourg. He mentioned this to show the peculiar position of the three places with reference to the defence of the English Channel. With regard to the rope-break referred to by Mr. Jackson, he could confirm, from experience, what had been said as to its value. He did not know that it emanated from Alderney; but whoever introduced it had conferred a great service on those who had occasion to deal with heavy weights, particularly in the water. Its use, however, was dangerous in wet weather. If it became wet and greasy there was a danger of its running away. In dry weather it was one of the most perfect breaks he had seen. Mr. Redman had said that the depth of the water at Portland was 50 feet. For four-fifths of the length of the breakwater it was 63 feet or 64 feet. No damage worth mentioning had arisen from the sea there, except to the temporary staging. A breach in the work itself towards the close was not due to the sea but to a settlement on the harbour side, and was occasioned by the subsidence of a bed of shale which lay very deep below the surface of the bay.

Sir John Hawkshaw, Past-President, said his connection with the Alderney breakwater arose from the circumstance of his having been requested by the Government, in connection with Col. Sir Andrew Clarke, to report on some mode of repairing or adding to it, which would have the effect of preventing the constantly recurring mishaps. Those being their instructions, they endeavoured to carry them out as well as they could, taking care, however, to state that they had not sufficient information to speak with anything like confidence. He suggested that cross-sections should be taken for a time to enable them to ascertain whether the mound was stationary or shifting, and, if shifting, to what extent. These were accordingly begun under Mr. Vernon Harcourt's superintendence. Sir John Hawkshaw stated to the Government that he thought it would take a couple of years to enable any one to say, with sufficient precision, what steps ought to be taken. Before the termination of the two

years, Government came to the conclusion not to carry on the works, and the proceedings were altogether stopped. It appeared to him at the time that the breaches were caused by seas being driven against the wall with great violence. From the shape of the mound and of the wall the seas were thrown up to a considerable altitude; in falling back again their momentum drew away the deposit from the base of the wall, and the bottom courses dropped down, having nothing to stand upon. The sea then got to the rubble hearting between the two legs of the wall, fetched out that, and in a short time worked through the other portion of the wall on the harbour side, making breaches clean through. The first breach that he examined was 45 feet wide, and went quite through the breakwater. It occurred to him, and Sir Andrew Clarke concurred in the opinion, that if blocks were put in at the face of the wall sufficiently large to resist the seas, the wall would be protected; but, before adopting even this plan, it was necessary to know whether, and to what extent, shifting of the mound took place. The cross-sections showed that at a point about 80 feet from the wall, and from thence outwards, the mound was stationary. It was only so much of the deposit as extended from the base of the wall to that point which was acted upon by the recoil of the waves. Such being the case, probably a mass of large blocks, taken up to a sufficient height, would have protected the wall from the sea, although the process would have involved a large expenditure. He believed that all the Government intended at present to do was to repair the breaches as they occurred from time to time—a course perhaps better than doing nothing. This was ultimately recommended by Sir Andrew Clarke and himself, until such time as the Government decided whether the place was to be maintained as a military harbour or not. It was not so easy, as Mr. Redman seemed to think, to decide what should be done with a work of that kind. He was sorry Mr. Redman had not explained the method, which would not only be easy, but inexpensive. If such a method could be pointed out it would most likely be adopted.

Col. Jervois, R.E., wished to refer more particularly to the policy of having a fortified harbour at Alderney. He had no doubt it would be a great advantage to the naval defence of the country. If, with the information now possessed, the question were asked, "Shall we undertake it?" his reply would be "No;" but having got it, if the question were asked, "Shall

we maintain it?" he would decidedly say "Yes." He would go further, and say, with Sir John Coode, that the eastern arm should be constructed, so as to complete the harbour. When the harbour was first proposed by Admiral Sir Edward Belcher, the use of steam for the propulsion of ships was in its infancy. The harbour suggested was of much smaller dimensions than that subsequently proposed, and it was on the south-east side of the island at Longy Bay. When Mr. Walker took the matter up, he thought that the harbour at Longy would not suffice for the coming requirements of the country, and he proposed the smaller harbour at Braye bay, which had gradually grown to its present dimensions. The practical point now was, What should be done with it? It was not a question requiring a soldier or a sailor to solve. Looking at it in connection with the harbours at Plymouth, Portland, and Portsmouth, and considering the effect which the power of keeping vessels at Alderney and at Portland might have upon the commerce of an enemy, the advantage of the harbour could not be doubted, and he believed the general opinion was that it should be maintained.

Sir Edward Belcher remarked that the Duke of Wellington had nothing to do with the harbour. On the 4th of August, 1842, Sir Edward Belcher was summoned to the Admiralty on secret service; and was ordered to proceed immediately with Colonel Colquhoun and General Carden to examine the Channel Islands, and determine what guns should be added or withdrawn, and what harbours should be made; and he was requested to report as early as possible, in order to enable the Government to lay before Parliament the estimates for the year. Sir George Cockburn desired that attention might first be directed to Guernsey, then to Jersey, and lastly to Alderney. All those harbours were calculated to accommodate ships of the line, and not mere fishing-boats. On arriving at Alderney, they found that the race running past the mouth of the proposed harbour would render it utterly impossible for any disabled vessel to get in, as there was an 8-knot current running across it. The 'Dasher' and the Admiralty yacht with difficulty stemmed the tide against the easterly wind, got into the harbour, and gained an anchorage. While they were at anchor, the grinding of the cables over the foul ground at the bottom satisfied them that it was no place for a ship-of-war. He then suggested Longy, which was in a similar situation to Cherbourg, and advised excavating 1,000 yards in, and 1,000 yards across, damming the harbour by the island of Rez. When all the stone had been removed from

the interior of the proposed site, there would have been a general depth of 30 feet of water, and a float equal to the Camber at Portsmouth. It was perfectly easy, from the contour of the land, to cut a canal from Longy into Braye harbour, and effect a western passage to the sea. The great object was "to be able to watch the French coast, to keep an eye upon Cap de la Hague, and be ready to send out ships to sea as soon as a vessel was seen coming out of that place." But at Braye that was utterly impossible. Ships could not be got to sea, and the enemy could not be so watched. He maintained that no sailor who had ever entered that harbour could regard it as a decent harbour for a ship of war. On arriving at the Admiralty in September 1842, he reported that the Longy harbour would cost £1,500,000. In 1847, when Mr. Walker commenced the works, he was asked by the Earl of Auckland to put his views on paper, and to explain them, to enable him to answer questions in the House of Lords. The Earl of Auckland had himself examined the place, and said he was of opinion that nothing satisfactory could be constructed there. In 1852 he was again summoned to the Admiralty by Sir Francis Baring, and was told that "the former Commission was still in force." The members of the Commission were thereupon ordered to go to Alderney harbour and report upon it. It was said, "You are not to entertain any of the opinions you entertained before; you are to examine the place, and tell us what has been done, and whether it is worth while to expend £600,000 more on the eastern arm." He requested Sir Francis Baring to send Mr. Walker also, in order that he might be there in a gale of wind. Mr. Walker was accordingly ordered to go; and reported against the eastern arm. On returning to England they also reported upon the fortifications, although they were expressly told not to say anything as to the fortifications, because they had been already rather defamed. But not a single gun upon the battery could play upon a vessel passing the mole-head; and in the martello tower there was no vent for the smoke, and the men would have been killed by explosions from the guns, or suffocated. They therefore thought fit to disobey orders, and to report upon these points, which he had to fight out afterwards with Sir John Burgoyne. In 1857, when the Admiralty again consulted him, and he was asked why he had reported against the eastern arm of the breakwater, he still maintained his opinion that the quantity of water which would rush in and out would upset the foundations, and that the existing large mouth was rather a safety-valve than otherwise. The present works were certainly a credit to British engineers,

and showed what Englishmen could do when they were determined—whether right or wrong.

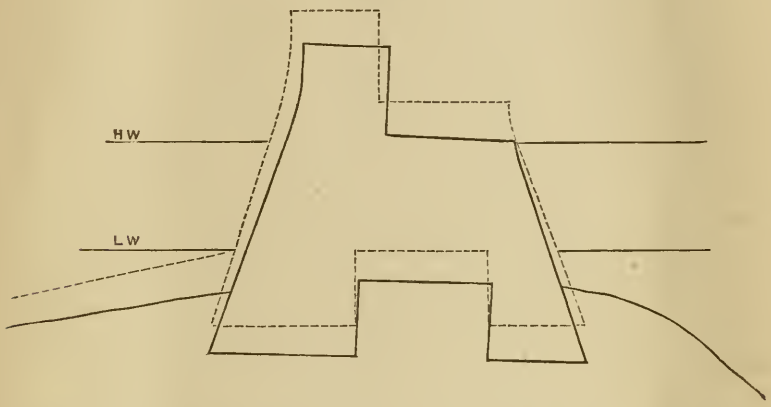
Col. Jervois said that in 1852, the time referred to by Sir Edward Belcher, there was only one fort begun, and that was about one-half built.

Mr. Vernon Harcourt, in reply, said the eastern breakwater was not abandoned till 1862. The estimated cost of the eastern breakwater in 1852 was £136,720, that of the most extended design was £300,000, and for the last design £100,000. He quite agreed with Sir John Coode and Colonel Jervois that the eastern arm should be constructed if the harbour was to be rendered perfect. Alderney harbour had laboured of late years under two disadvantages; in the first place it was called a harbour of refuge, which from its position it was not fitted to be, as all vessels, except those bound for the Channel Islands and the neighbouring French ports, should keep to the west of the Casquets; and in the second place it had been considered a bad harbour in easterly gales. This it undoubtedly was, through no fault either in the site or the design, but simply owing to the abandonment of the eastern breakwater. The value of Alderney harbour depended on its geographical position: lying on the opposite side of the Channel to the English coast, and near France, its importance as a naval and military outpost had been for a long time acknowledged by competent authorities. Sir Edward Belcher, in stating that it was impossible for vessels near Cap de la Hague to be seen from Braye, was probably unaware that the French coast, and the lighthouse at the point, were quite plainly visible from the head of the breakwater; and that Fort Albert, situated on the summit of Mount Touraille and looking down on the harbour, commanded an excellent view of the French coast for many miles. He did not agree with Sir Edward Belcher's observation, that an eastern breakwater, by narrowing the entrance, would cause a very rapid flow of tide through the mouth of the harbour, as the harbour was not large, and the rise of tide at Alderney was not peculiarly great. He was aware that Longy bay had been proposed at first as the site for the harbour; but, though sheltered from the west, two very long breakwaters would have been required to protect any considerable area, and the race of Alderney would have run past the entrance.

Figure 1 (p. 99) showed the actual position to which the superstructure tended to settle; the harbour wall settled rather more than the sea wall, so that the courses of masonry dipped more or less towards the harbour. This was apparent at the present time in the courses at the head, and in the overhanging of the harbour

side of the promenade wall, and was probably owing to the sea beating against the sea side of the superstructure, to the stroke of the falling water on the quay level, and to the steep slope of the foreshore on the harbour side, which was so formed in order that

Fig. 1.



vessels might lie alongside the quay. He wished to add his testimony to that of Mr. Jackson as to the almost incredible power of the sea at Alderney in bringing large stones from the sea foreshore right over the superstructure; the quay level after a storm had always stones lying here and there upon it, and, opposite the Braye rocks, the harbour foreshore had actually been raised several feet in this way. The work of maintenance consisted of two distinct operations: the repair of breaches, and the renewal of foreshore. The repairs of the superstructure, as he had mentioned, cost £57,200. Of this sum, however, £11,300 had been expended in repairs to unfinished work. From 1864 to 1872 £44,225 had been expended in repairs to finished work, so that the average annual cost of the maintenance of the superstructure for eight years amounted to £5,500; this charge would, probably, somewhat diminish in time, as each repair tended to strengthen the structure; it might, however, be reckoned for the present at £5,000 a year on the average. He considered that at least 25,000 tons of large stone would be required to be deposited each year in order to maintain the sea slope of the mound; this would cost about £3,000, making the total cost of maintenance amount to £8,000 a-year.

With the view of ascertaining to what extent the cost of the repair of the superstructure varied with the depth of water, he had

recently made a calculation of the cost of the repair of each 1,000 feet of superstructure, and the following table showed the results arrived at:—

Distance from Shore.	Date of Completion.	Total Cost of Maintenance.	Period of Maintenance.	Average Annual Cost of Maintenance.
Feet feet.	A.D.	£.	Years.	£.
0 to 1,000	1852	1,850	20	93
1,000 to 2,000	1855	2,550	17	150
2,000 to 3,000	1860	—	12	—
3,000 to 4,000	1862	17,160	10	1,716
4,000 to 4,700	1864	24,340	8	3,042

From this table it appeared that the last length of 1,700 feet (in reality the last 1,400 feet) was the only portion which was expensive to maintain; chiefly in consequence of the great depth of water, and perhaps partly owing to the greater exposure, and slight variation in the direction of the breakwater. It had naturally been suggested that the inner portion only should be retained; the objections to this course were that the harbour would be diminished, that a new head would have to be built, and that a surf might possibly be caused across the new entrance by the waves breaking on the outer portion when partly levelled by the sea. He estimated the cost of carrying out this proposal at £2,900 per annum.[1]

The moorings at present laid down in the harbour were all well within the shelter afforded by the inner 3,300 feet of the breakwater; and, should the Government consider that the cost of maintaining the breakwater was greater than the possible value of the harbour, then the only wise alternative course to pursue would be to maintain the inner portion of the breakwater at a moderate charge. To secure permanently the whole of the breakwater, a foreshore of large concrete blocks would be required; his impression being that no amount of rubble stones, of the average size that could be procured, would stand for any length of time near the face of the sea wall.

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[1] Estimated annual cost of maintaining the inner 3,300 feet of breakwater:—

	£.
Repairs to superstructure, say	400
Large stone on foreshore, 15,000 tons	1,800
Head, £20,000 at 3½ per cent. per annum	700
Total	£2,900

Mr. J. A. McConnochie stated, through the Secretary, that he had been engaged on the various designs and estimates for the works from 1855 till 1868, at first under the direction of Messrs. Walker, Burges, and Cooper, and afterwards of Messrs. McClean and Stileman. The breakwater walls had been completed for the entire length of 4,700 feet in September 1864, about two years after the lamented deaths of Mr. Walker and Mr. Cooper. The damage caused by the sea to the works was so slight up to the time of Mr. Walker's death, and, indeed, up to the date of the completion of the walls, as to warrant the confidence Mr. Walker had in their stability with the most ordinary maintenance. The entire cost of damage by the sea to the walls, up to the date of their completion, amounted to £14,863; of this the sum of £12,279 was due to damage to the temporary heads or ends of the season's work on four occasions, and was incidental, as the Author properly observed, to unfinished works of this character. The remaining £2,583 represented the entire cost for repair of damage to the permanent work of the walls, 4,700 feet long, up to their completion in September, 1864. This compared favourably with works far less exposed; and, there being no previous experience of a work carried out in such a great depth of water, and in such a situation, the figures proved that during the entire construction of the work nothing occurred to disturb Mr. Walker's confidence in the section he had adopted. The last design which Mr. Walker personally directed was for the head of the breakwater, in September 1862, a few days before his death. This portion of the work, in what might be considered its most exposed situation, executed in 1864, in a depth of 130 feet of water at low tide, had stood unmoved on the rubble mound, and was likely to remain so. When the first serious damage occurred, four months after the completion of the walls, the question of repairing them with heavier blocks of stone was considered; but the urgency of the case, the quantity of material on hand, and the absence of plant or tackle on the works for dealing with heavier materials, led to the repairs being executed similarly to the rest of the work, but with the addition of dowels, joggles, and bolts. It was considered also that the base having borne the weight of the superstructure for nearly two years, the repairs were not likely to be affected by subsidence to any serious extent. Subsequent repairs had doubtless, for similar reasons, been dealt with in a like manner; but as all the old plant had been disposed of, and new plant would be required for the works of maintenance, this would probably be provided of sufficient power to lift blocks of 30 tons to 40 tons weight. The breaches

never extended down to the bottom of the walls, the two lower diving courses being generally left uninjured. This materially facilitated the execution of the repairs in the short working season at Alderney. The Author had referred to the unenviable notoriety which the work had acquired; but this notoriety was acquired on the question of Government policy, long before the work suffered any serious damage. The walls, for 3,400 feet from the shore, had really suffered no damage worth naming, although the depth of the original bottom at 3,400 feet was 90 feet under low water, or 30 feet in excess of the greatest depth at Portland. This was a result that need not attract any unenviable notoriety to the engineering; and if the outer portion of the work, in the unprecedented depth of 120 feet to 130 feet, had suffered damages, the total repairs from the commencement of the works to 1872, seven years after the completion of the walls, amounted to only £57,200, of which the proportion chargeable to the seven years after completion was about £6,000 per annum. This was not a large sum when compared with that for Plymouth breakwater, in about one-third of the depth of water, and much less exposure, where the cost of maintenance amounted to from £5,000 to £7,000 per annum. Probably the above sum would be a diminishing one, resolving itself ultimately, when settlement had ceased, into a charge for feeding the foreshores only. Sir John Coode had directed attention to the narrowness of the harbour. This was explained by reference to Plate 7, which showed that the original design was for a small harbour of observation, for comparatively shallow draught vessels; and only after the works were considerably advanced were the progressive extensions of the designs suggested, until the days of iron-clad frigates, when 5 fathoms depth of water and room for the iron-clads to swing in were required. Besides the reason already suggested for the construction of an eastern breakwater, there was another, which had more than once been brought under the notice of the Government. The base and foreshores on the harbour side of the breakwater were designed to face an inclosed area, and were not intended to be open to the sea in easterly gales, as they were now. The expense of an eastern breakwater, which formed part of all Mr. Walker's designs, was comparatively small; and, constructed as it would be now, with past experience as a guide, questions of expensive maintenance would not arise. With reference to Sir John Coode's remarks on the proportion of materials in the base, every care which the long experience at Alderney suggested was taken to secure solidity in the mass, each barge load being a

careful selection of stones, varying from 2 tons to an ounce in weight. Sand and shingle, tried at first in the mixture, were ultimately abandoned, because they were floated away by the current before reaching the bottom; and any small quantity of this material which could have been deposited at the hardly perceptible slack water could have had little, if any, effect on the mass. A comparison of this work and its exposure with any of the existing breakwaters protecting harbours of refuge was like comparing the latter with the sheltered breakwater at Harwich. There was no difficulty now, in the light of the experience which Alderney breakwater had afforded, in seeing where improvements could be made in the section. So far as the quality of the work executed was concerned, every one who had examined it must admit that it reflected the greatest credit alike on the resident engineers in charge, and on the contractors who executed it; and it was to be regretted that Mr. May, at present at Alderney on a visit, was prevented by stormy weather from leaving the island to attend the Meeting.

Mr. W. Parkes, through the Secretary, expressed regret that, owing to absence from England, he was unable to attend when the Paper was read and discussed. He had acted, in the years 1848 and 1849, as resident engineer of these works, under Messrs. Walker and Burges, and he looked back upon those two years as the most instructive and important of his professional life. It was during that time, as the author of the Paper had stated, that the inadequacy of the originally designed section to withstand the great force of sea became apparent. The real cause of the first failure was, however, not described in the Paper. The portion of sea wall built according to the original idea, about 200 feet or 300 feet from the commencement, and in a very exposed situation, had never, for upwards of twenty years, shown any sign of weakness; but there was a difficulty during construction in maintaining the exposed and unfinished end even during ordinary gales. Two or three months' work might be undone in as many hours. He believed no damage ever occurred to this portion of the work, except what began from the open end. This objection, however, was sufficient to condemn the system. Mr. Parkes was much gratified to find how fair a view had been taken, both by the Author and the late engineer-in-chief, Sir John Hawkshaw, of the engineering merits of their predecessors' work. No doubt many faults might be demonstrated by an *ex post facto* criticism, but these gentlemen having generously kept in view the fact that their criticism was *ex post facto*, it had only served to invite co-operation

in the more pleasing task of endeavouring to deduce lessons for future guidance from what must be admitted to have been partial failures. On one important point there appeared to be a discrepancy between two of the best informed speakers. Sir John Hawkshaw said that the deposit was drawn away from the base of the wall, and then the lower courses, having nothing to stand on, dropped down. Mr. McConnochie, on the other hand, stated that the lower courses had never been disturbed, and Mr. Parkes could confirm the truth of this latter statement up to a recent date. If, therefore, the effect described by Sir John Hawkshaw had really taken place, it could only be in exceptional and recent cases, and hardly justified the conclusion drawn by subsequent speakers, that the foundations were laid at an insufficient depth. Mr. Parkes opinion was that the depth of foundation was amply sufficient, and that the character of the superstructure was at fault. The stability of the superstructure depended on the maintenance of its rigidity, and this it could not do on a yielding foundation. Had the superstructure, instead of being one continuous rigid whole, consisted of a succession of detached masses, each mass might have sunk without causing dislocation, and the consequent exposure of comparatively small blocks to the destructive action of the sea. He thought each fortnight's work should have terminated with a vertical face instead of an inclined "scar," on to the steps of which the next fortnight's work was bonded. Also, that the sea wall should have stood on its own horizontal foundation, quite independent of the hearting and of the harbour wall, instead of all three, though founded at different levels on the rubble stone, being bonded together into one rigid mass above water. He agreed with Sir John Hawkshaw that the high parapet was a source of weakness. It would be far better that the waves should have a free vent over the top of the work into the harbour, than that they should be thrown up so high into the air, to fall again with increased force on the work, and the foreshore at its foot. The rigid continuity of the work, however, was a fault of a temporary character, which would disappear as the rubble base became consolidated, and the tendency to unequal settlement ceased. He was therefore glad to find that the idea of great additions to the foreshore had been for the time abandoned. He considered them quite unnecessary, and calculated only to meet imaginary evils. Sir John Coode had spoken of the want of compactness in the rubble base. Mr. Parkes believed that uniformity of compressibility was of greater importance than compactness; and in this belief he was averse to the use of large stones mixed with

smaller ones, which he thought could not but cause unequal consolidation.

Mr. Bindon Stoney remarked, through the Secretary, that this Paper faithfully recorded the inherent sources of failure in a breakwater which belonged to one of the standard types; one, moreover, which appeared to have been designed and executed with much care, and with the best available knowledge at the time. The principal causes of failure were, first, the insufficient depth below low water at which the base of the superstructure was laid; and secondly, the subsidence of the rubble mound, which caused cracks and fissures in the continuous masonry above, such fissures eventually opening out into wide breaches under the influence of storms. It appeared problematical whether any of the recognised systems of constructing breakwaters would meet the exigencies of localities such as Alderney; and Mr. Stoney would suggest, as worthy of trial in similar situations, the system of large blocks, which he had successfully applied to the construction of quay walls in Dublin. These blocks were 27 feet high, and weighed 350 tons each. The experience he had gained led him to conclude that blocks of considerably larger weight might be constructed on shore, and be afterwards conveyed to their destination in a breakwater, where they might be laid on the top of the rubble mound, with their base from 20 feet to 30 feet below low water; that was, at a depth where the disturbing action of the waves on the rubble was not felt. These blocks might be laid either regularly or irregularly; if the former, their tops would project a few feet above low water, and it would probably be desirable to allow several months to elapse after they had been laid, in order to allow time for settlement before building the superstructure. It would also be advisable to raise the foreshore 10 feet or 12 feet high at the toe of the blocks, so that the latter might be, as it were, imbedded in the rubble. One of the advantages appertaining to separate large blocks consisted in this, namely, that subsidence of the rubble foundation would allow each block to settle down locally without endangering the adjoining blocks; and when they had come to a final settlement the continuous masonry above low water would present an unbroken surface for the sea to strike against. The chief difficulty in exposed situations would arise from waves or strong currents interfering with the setting of the blocks; but it was thought that, in most situations, there were many days in each year when the weather would be suitable for the operation, and as a single block would extend along several feet in length of the breakwater,

good progress might be made annually. A double row of blocks, with rubble filling between, would enable the breakwater to be made of any desirable width on the top.

Mr. T. R. Winder observed, through the Secretary, that the Paper tended to show that the upright, or upper works built upon the rubble, were not founded at a sufficient depth below low water; that the sea was able to withdraw the rubble from the base of the wall as far as 90 feet seawards, and to a depth at that point of 20 feet below low water; and that the walls cracked, requiring repairs; whilst heavy stones must, or should be added after every storm, to make good the disturbed slope. By inference it was shown that other breakwater walls built upon the British coasts were weak in this particular, and that 20 feet to 24 feet, instead of 12 feet to 15 feet, would be the better depth below low water of spring tides at which to found them.

Mr. Winder presented some details he arrived at, by actual measure, whilst engaged in the construction of the breakwater in St. Ives Bay. In this instance the sea moved sand and silt only, and so far its work was less. Still the effect, as indicated by the profile before and after the storm, might to some extent show the line of force and direction of the withdrawal. The inclination of the face was 1 in 4. The top was 5 feet above high water, 23 feet above low water, and 33 feet above the bed of the foreshore. The vertical depth of the foreshore removed was supposed to be 26 feet below low water of spring tides; the measured depth to the surface of the stone withdrawn from within the piling and passing under the stone was 22 feet. The question brought to Mr. Winder's mind was, Did the sea during the height of the storm, whilst scooping out the stones from under the base of the work, carry them in nearly a horizontal direction from it to a considerable distance; and afterwards, as the storm abated, overlap the sands back over them? Or did the sea take the stone up the outer slope of a trenched hollow? After the height of the storm had passed, the stone was not found by sounding to lie upon the external slope of the hollow; and before the storm was fully over, the sea had nearly refilled the excavation. Whether it were prudent to found breakwaters upon a sand or silt foreshore within 22 feet of low water of springs appeared fully proved in the negative, even when placed under protecting headlands, and in a fairly enclosed bay, unless cubes of sufficient weight to withstand the sea were placed above the line of foundations, or, as in this case, above the bottom of the piling. The mode of repair was by tipping rough quarry stones weighing up to

5 tons, rolled over cantilevers advanced from the top far enough to permit a free fall without contact with the wood, and when their apex reached above water, to roll them in against the face at low-water level. The work thus treated had stood for six years; but the sea face of piling had become a column; its base fixed firmly in rubble 12 feet below the surface, and thus made able to sustain the pressure of the rubble from within. During the withdrawal of the stone from within the sea face, much as lime was drawn from a kiln, the inner wood and iron fastenings were greatly damaged; and he was convinced that timber structures for breakwaters could not in any case be the best; in but very rare instances could they be expedient; and in such cases it would be desirable to reject all permanent bracing for supporting the sea face, and to support this by heavy stone placed outside to such an extent that the wood intersected about one-third of the base transversely.

Mr. Vernon Harcourt wished to add, through the Secretary, a few observations with reference to Mr. Parkes' remarks. The first 300 feet of the breakwater, built in accordance with the original design, though undisturbed for many years, had at last been injured by the sea in the winter of 1872–3, a hole having been made in the superstructure close to the shore. He attributed the immunity from damage of this portion of the work, when finished, more to the absence of settlement, owing to the small depth of water, and to the protection afforded by the high and very gradually sloping foreshore, than to the strength of the superstructure itself. With reference to the apparent discrepancy, remarked upon by Mr. Parkes, between the statements of Sir John Hawkshaw and Mr. McConnochie, he would observe that, within the last two or three years, the foreshore had been actually lowered, in one or two places, below the foundations of the superstructure; and he imagined that Sir John Hawkshaw also referred to the gradual settlement of the base causing an unequal settlement in the lower unconnected courses of the superstructure, which was not equally followed by the rigidly connected mass above, thus producing, as mentioned in the Paper, openings in the face joints, and cracks in the interior, which greatly tended to cause breaches. On the other hand, Mr. McConnochie's statement was also correct, as generally the breaches had commenced near low-water mark, where the face stones were not united by cement, and were left unprotected by the foreshore, but the lowest courses were kept in place by the foreshore in front of them. As to Mr. Parkes' opinion that the depth of the foundations was amply

sufficient, he would observe that in many places the foreshore, close to the face of the sea wall, had already, in 1872, been removed to 12 feet below low water, the depth at which the foundations were originally laid. It was, however, so important to maintain the foreshore at the face of the sea wall as nearly up to low-water level as possible, to protect the lower courses of face stones from being withdrawn by the action of the sea, that the question of maintaining it to prevent undermining of the superstructure need not be considered. Had the superstructure, on the contrary, been invulnerable, then, in order to secure it from being undermined, without maintaining the foreshore, the foundations of the outer portion should have been about 20 feet below low water, the depth at which all action of the sea on the foreshore ceased.

December 2, 1873.

T. HAWKSLEY, President,
in the Chair.

The following Candidates were balloted for and duly elected:—Henry Thomas Geoghegan, Perceval Moses Parsons, Cyril James Shaw, and Benjamin Walker, as Members; Thomas Airey, Edward Robert Austin, Edmund Scott Barber, Hilary Bauerman, Nathaniel St. Bernard Beardmore, Stud. Inst. C.E., William Atkinson Bell, John Brown, Robert Burton Buckley, Gabriel Gordon Cleather, William Ovenden Collard, William Milner Crowe, Cecil West Darley, Charles Elwin, Stud. Inst. C.E., James John Alexander Flower, James Fraser, Walter Faithfull Garland, Stud. Inst. C.E., John Cameron Graham, Irwin Montgomery Greig, Major R.E., Henry Woodcroft Hammond, The Hon. Arthur Wyndham Holmes à Court, Osbert Henry Howarth, Stud. Inst. C.E., Samuel Hunter, Charles Henry Grey Jenkinson, Stud. Inst. C.E., Thomas Lewis Johnson, Edward Henry Keating, William Hubert Kinch, Stud. Inst. C.E., Frank Howard Landon, Stud. Inst. C.E., Charles Lean, jun., Albert Lewis Newdigate, M.A., William John Adamson Parker, Manuel Hipolito Peña, Alphonso Raymond, Stud. Inst. C.E., Henry Strutt Collette Ree, Charles Remfry, John Kirby Rodwell, Stud. Inst. C.E., Aloys Sprenger, Frederick Toplis, Stud. Inst. C.E., Ralph Hart Tweddell, Nowrosjee Nesserwanjee Wadia, David Wallace, and David Ward, Major R.E., as Associates.

It was announced that the Council, acting under the provisions

of Sect. III. Cl. 7 of the Bye-Laws, had transferred HENRY BRADY and JAMES SAMUEL COOKE from the class of Associate to that of Member.

Also that the following Candidates, having been duly recommended, had been admitted by the Council under the provisions of Sect. IV. of the Bye-Laws, as Students of the Institution :—GEORGE PROCTER CARLESS, ADOLPHUS JAMES CHANCELLOR, GERARD COWPER, GEORGE LACY GOOD, WILLOUGHBY ROCHESTER HUGHES, ALFRED WILLIAM LAWFORD, HERBERT NEAL, ROBERT CHARLES FREDRICK OGILVIE, EDWYN HERMANN PARGITER, JOHN WILLIAM RANDELL, EDWARD ROBINS, and Sir THOMAS RAIKES THOMPSON, Bart.

The discussion upon the Paper, No. 1,347, "Account of the Construction and Maintenance of the Harbour at Braye Bay, Alderney," by Mr. Leveson Francis Vernon Harcourt, M.A., was resumed and concluded.

December 9, 1873.

T. HAWKSLEY, President,
in the Chair.

No. 1,358.—"On the Geological Conditions affecting the Construction of a Tunnel between England and France." By Joseph Prestwich, F.R.S., V.P.G.S., Assoc. Inst. C.E.[1]

The object of this Paper is to review the geological conditions of the several formations in the south-east of England and north-west of France, and to give certain facts bearing on the possible construction of a submarine tunnel, with the view of serving as data for any future projects or operations. In this case, many supplementary investigations would be necessary, and these pages, while they show the extent of present knowledge, may serve to indicate in what direction those inquiries should be made. The observations on the Palæozoic rocks made during the last few years by the Author in the north of France and south of England, in connection with the Reports of the Royal Coal Commission, have also suggested an entirely new course of action, which, whatever may be its drawbacks—and they are not inconsiderable—offers, there is reason to believe, the one material advantage of security against the irruption of the Channel waters.

On the geological structure depend the primary conditions of such a work. These ascertained, the not less important mechanical and engineering questions remain to be considered. Granting the possibility of the work in a geological point of view, there are great and formidable engineering difficulties; but the vast progress made in engineering science during the last half century leads the Author to imagine that they would not prove insurmountable, if the necessity for such a work were to arise, and the cost were not a bar.

In considering the geological question, the points first to be considered are the lithological characters, dimensions, range, and probable depth of the several formations; and it is proposed to notice, on this side of the Channel, all those from the estuary of

[1] The discussion upon this Paper occupied portions of two evenings, but an abstract of the whole is given consecutively.

the Thames on the north to the coast of Sussex on the south; and on the other side, all those ranging from French Flanders to the Bas Boulonnais and the coast of Normandy. This is done, irrespective of their relative merits in any other than a geological point of view.

The several formations are taken successively in descending order. The Cretaceous and Wealden series are touched on but briefly, as they have been treated at length in reference to this question by Mr. Topley in his "Geology of the Straits of Dover."[1] The Lower Cretaceous and Jurassic series have also been the object of similar researches on the part of M. Thomé de Gamond.[2]

The London Clay.—This formation attains in the lower part of the Thames valley a thickness of not less than from 450 feet to 500 feet, and its equivalent on the Continent, the 'Système Ypresien' of Dumont, has in French Flanders dimensions little, or if any, less than in England. It consists, as is well known, of a tenacious and homogeneous clay,[3] extending on the English coast, uninterruptedly, from the mouth of the Thames to Harwich. It has been proved by wells to be 293 feet thick at Sheerness.[4] On the opposite shore, at Southend,[4] it attains a thickness of 413 feet; at Foulness Island, of about 350 feet (but is there covered by 60 feet to 80 feet of sand and gravel); and opposite Mersea Island to about 250 feet, thinning off to 23 feet at Harwich. Inland, at Chelmsford, the London clay is 186 feet thick, at Maldon 234 feet, and at Colchester a little more than 100 feet. (See Appendix, page 137.)

On the French coast the London clay comes to the surface in a line from Bergues, near Dunkirk, to Watten, near Calais, whence it passes seaward beneath the alluvial sands and shingle which extend to the coast. At Calais[5] these alluvial beds are 86 feet thick, and overlie 161 feet of Tertiary clays, sands, and pebble beds. The upper of these tertiary beds may probably be referred to the London clay; but it is there only a few feet thick. At Dunkirk the London clay has been sunk into, but not traversed, to a thickness of 264 feet,[6] and over it there are 118 feet of shelly sands and

[1] Quart. Journ. of Science, April, 1872.

[2] Étude pour l'avant-projet d'un Tunnel sous-marin entre l'Angleterre et la France, Paris, 1857. Also a further account published in 1867, and a translation published, London, 1870.

[3] In France and Belgium it is in places more sandy, but it is not until it reaches the neighbourhood of Mons that any material difference is perceptible.

[4] Whitaker, "Mem. of the Geological Survey," vol. iv., pp. 468 and 441.

[5] "The Waterbearing Strata of London," p. 208.

[6] M. Meugy, taking the dip from a point in the interior, gives a depth to the Lower Tertiaries which would be equivalent to a thickness of 728 feet to the

shingle; while at Ostend its exact thickness has been ascertained by a well-boring to be 448 feet, and it is capped by 110 feet of the shelly sands and shingle. From the coast the London clay ranges inland, and is 322 feet thick at Hazebruck, and 300 feet or more at Cassel. The lithological character of the London clay in French Flanders is very similar to that which it has in England—a tenacious blue and grey clay—brown, where weathered near the surface. M. Meugy [1] says that it is "une argile compacte, de couleur gris bleuâtre ou gris jaunâtre et à texture souvent feuilletée. Elle est imperméable à l'eau." MM. Ortlieb and Chellonneux [2] also remark, "Cette argile est aussi remarquable par sa masse que par son homogénéité" . . . "cette roche est imperméable à l'eau." [3]

The rise of the Chalk in the Isle of Thanet breaks the continuity of the London clay in its range eastward beyond Sheppey and Herne Bay, and thus the direct communication through this formation between Kent and the French coast is intercepted. Mr. Whitaker [4] has, however, shown that the Chalk in the Isle of Thanet forms an arch or dome, dipping to the north at Margate, and to the eastward at the North Foreland. It is probable, therefore, that the outcrop of the Lower Tertiaries is very near the coast, and that the London clay sets in at a distance of from 2 to 3 miles from the shore,[5] dipping northward towards the Essex coast, and eastward towards the coast of French Flanders—the intermediate sea-bed forming a trough of London clay, capped, possibly, in its northern position by the thin sandy Upper Tertiary beds, which set in in North Essex and the coast of Belgium.[6]

This trough of London clay is not less than from 300 feet to 400 feet thick at the Essex end, and from 350 feet to 450 feet thick

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London clay at Dunkirk. This is hardly probable: it is more likely to be between 400 feet and 500 feet. The dip is subject to variation.

[1] "Essai de Géologie pratique sur la Flandre Française." Lille, 1852. P. 142.

[2] "Étude Géologique des Collines Tertiaires du Département du Nord." Lille, 1870. Pp. 15, 16.

[3] The few subordinate seams of sand and pebbles which the London clay contains both here and in French Flanders, give little or no water, and are rarely persistent. They are, in fact, generally merely local seams, without any persistent range.

[4] "Quarterly Journal Geological Society," vol. xxi., p. 395, and op. cit., p. 35.

[5] According to this view the outcrop of the London clay would pass by the Margate Sands and the Goodwin Sands. Can these shoals be in any way due to central unremoved portions of the London clay? It appears by the MS. in the Author's possession that the same idea had occurred to the late Dr. Mitchell on independent grounds.

[6] The presence of certain extraneous fossils in the Crag of Suffolk renders this probable.

at the French end; and as the dip seaward is equal at least to the dip of the sea-bed between the two coasts, it is probable that in the intermediate area but little of the London clay has been removed by the Channel denudation.[1]

Supposing there are no faults of importance between the Essex and the French coasts (and there is no reason to suspect that there are any of magnitude), there would be a continuous mass, 400 feet, or more, in thickness, of this tenacious and impermeable clay, extending the whole distance between the two countries, and presenting every condition favourable for the execution of submarine tunnelling. On a small scale, its adaptability to tunnelling under water was proved in the case of the Tower Subway, where a passage under the Thames, 1,320 feet long and 7½ feet in diameter, was successfully made, without a single obstruction or mishap, in the course of five and a half months; and although in one part not more than 20 feet from the bottom of the river, there was no leakage and no water in any part of the work.

The nearest points, however, between the two coasts where the London clay is thus largely developed are 80 miles apart; and it is probable that, taking into consideration the approaches, and the necessity, in order to avoid the overlying alluvial beds, of not taking a straight line, a submarine tunnel in the London clay could not be much under 100 miles in length. Two alternative and possibly equally formidable lines offer,—one starting from St. Osyth, where the London clay is about 250 feet thick, and the other from Southend, where the clay is above 400 feet thick, both running in a straight line to a point on the Falls Shoal; and thence straight by Dunkirk to, or beyond Bergues (6 miles inland), where the London clay comes to the surface from under the great fringing belt of alluvial sands and shingle. (See Map, Pl. 8., and Sec. 1, Pl. 9.)

Under the London clay are the Lower Tertiary beds, which are together about 100 feet thick. They consist of quartzose sands, pebble beds, and subordinate mottled clays, all too irregular, too unimportant, or too permeable for tunnel work.

Chalk.—This formation, which everywhere in the south-east of England and north-west of France underlies the Tertiary series,

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[1] Had the small trough of Lower Tertiary strata which passes inland at Pegwell Bay included the London clay, the passage from the French coast at Gravelines, or Dunkirk, to Pegwell Bay, would have been easy. The continuity is broken at or near the Goodwin Sands, so that thence to the English shore the only possible connecting link, and that a very poor and dangerous one, would be the lower part of the Thanet Sands (base of Lower Tertiaries), which are there more argillaceous than usual.

has a maximum thickness of from 1,000 feet to 1,300 feet; but, as much of it has in this area been worn away or denuded before the deposition of the tertiary strata, its actual thickness in the district under notice varies from 300 or 400 feet, to 800 or 1,000 feet.

The upper beds consist of almost pure carbonate of lime, easily worn by water, and, being also soft and fissured, they are readily permeable. But the Lower Chalk or Chalk Marl contains so large a proportion of argillaceous matter and silica in a state of fine division that some beds pass almost into a clay, and when unbroken and compact, very little water can pass through them, and then only with extreme slowness, though this will increase under pressure. But, although a small bore-hole, or even a shaft, may often be carried through a considerable thickness of Lower Chalk, and no water obtained, the occurrence of fissures is too uncertain to render it a reliable medium over a larger area.[1] In some cases, when the Lower Chalk comes to the surface, and is more broken and fissured, the quantity of water it yields is very large, as in the instance of the Tring cutting, described by Robert Stephenson, where the discharge was at the rate of 1,000,000 gallons per day; or at Folkestone, where the town water supply is obtained from the Lower Chalk of the adjacent downs. On the other hand, the Chalk Marl in France and Belgium acts as an impermeable stratum in stopping the passage of water from the very permeable Upper Chalk into the underlying Coal Measures; and no water was found in it either at Kentish Town, Harwich, Southampton, or Calais; but the diameter of the bore-holes, by which they were traversed, were very small. At Calais one spring was met with at a depth of 70 feet in the Upper Chalk, and the water was brackish, showing communication with the sea.

Nor must it be forgotten that wells in the Chalk under London have to be carried or bored to depths of from 10 to 300 feet, before meeting with water-bearing fissures, or else headings have to be driven in search of one. Again, the escarpment of the North Downs, and that of the chalk hills of Wiltshire, Oxfordshire, and Buckinghamshire, are fringed with numerous springs, which issue at their base. These springs, although thrown out generally by the Chalk Marl, are apparently, not always, on the top of it, but often low down in the deposit, and they constantly wear their point of issue from a higher to a lower level. Whatever the level of the spring, the water of course passes through all the superincumbent portion of the Chalk Marl.

[1] The Author's opinion on the Chalk is expressed at length in the "Water-bearing Strata of London."

It would be instructive to determine the levels of these various springs.

This very commonly impermeable character of the Chalk Marl has given rise to the hope that it might prove compact enough for a submarine tunnel under the Channel between Cape Blanc-Nez and the South Foreland; but when it is considered that such a work would have to face the risks arising from the lateral passage of the inland springs,[1] and from the chance fissures, so common to calcareous rocks communicating with the sea, it is feared that the difficulties would prove to be of a very formidable nature. It is to be observed that in the Channel the chalk is frequently bare, besides being unprotected by any overlying strata.

The Upper Greensand is here too thin (1 to 3 feet) to require notice. It is a chalk marl, mixed with green grains.

The Gault.—This formation consists of a bluish-grey clay, very tenacious and impermeable. As it is, however, only 130 feet thick on the English coast, and as this is reduced to about 40 feet on the French coast, the attempt to carry a tunnel through it under the Channel would hardly be feasible.

The Lower Greensands are composed, 1st, of the Folkestone beds, which consist of extremely permeable sands; 2nd and 3rd, of the Sandgate and Hythe beds of mixed grey clays, sands, and ragstone; 4th, of the Atherfield clay. The latter alone is impermeable; but although these beds form on the English coast a mass of strata together, 260 feet in thickness,[2] they thin off so much to the eastward, that on the French coast they are reduced to 30 or 40 feet, exclusive of the Atherfield clay,[3] which is, however, only 30 feet thick at Hythe.

The Wealden Strata, largely developed in England, where they attain a thickness of not less than 1,200 feet, are reduced to a thickness not exceeding 40 feet or 50 feet in the Boulogne district,[4] and,

[1] Although it might be possible to overcome many of the inland springs, there would be the danger that, owing to the ramifications of the fissures through which they pass, some may communicate with the sea-bed, so that draining of these lesser waters would only leave channels for the more dangerous influx of the sea waters through the very fissures by which the inland waters now find vent as submarine springs.

[2] Dr. Fitton, "Trans. Geol. Soc.," 2nd Series, vol. iv., p. 319, and Drew, "Mem. Geol. Survey," Sheet 4.

[3] There are specimens in the Boulogne Museum of the *Ostrea Leymerii*, from Wissant, indicating probably the presence there of the Atherfield clay, which is, however, only occasionally exposed on the shore.

[4] For a description of these and the underlying rocks of the Boulonnais, see M. Rozet's "Description Géognostique du Bassin du Bas Boulonnais," Paris, 1828;

instead of presenting large masses of soft permeable sandstones, and impermeable grey and mottled clays, they consist of permeable rubbly ironstones and grits, with thin subordinate beds of clay and sand. These beds cap the cliffs and hills in the interior of the Boulonnais, and their continuity between these points and our coast is broken by the rise of the Kimmeridge clay. If, however, the sandy beds on the coast south of Wissant should prove to be Wealden, and to cover more argillaceous Wealden strata, then possibly the latter might deserve inquiry; but this is very problematical, as is also the line which such Wealden strata may take from this point to the English coast. They may form a narrow band wrapping round the north end of the Varne. There is a possibility of this, owing to the break in geological sequence between the Wealden and Jurassic strata, the former of which covers, in the neighbourhood of Boulogne, unconformably and at different levels, a denuded surface of the Kimmeridge and Portland beds, and passes transgressively on to the Oolites, and then to the Palæozoic rocks in the neighbourhood of Marquise and Ferques. This point has an important bearing, which we shall have occasion to refer to again.

Under the Wealden commences the series of Jurassic strata, the uppermost of which consists, in the Boulonnais, mostly of loose and very permeable beds of sand, with layers and detached blocks of massive concretionary sandstone, constituting,—

The Portland Beds.—It would be impossible to traverse these sands and sandstones under the Channel, as water would pass through them as through a quicksand. They are from 60 feet to 100 feet thick and repose upon,—

The Kimmeridge Clay.—This argillaceous formation is largely developed in the north-west of France, though it rarely appears on the surface. It underlies the chalk at Rouen,[1] and was there found, by a boring for coal, to be about 1,000 feet thick. It crops out from beneath the Cretaceous rocks for a short space in the Pays de Bray, where it was proved many years since, to the depth of about 600 feet. It reappears again in the Boulonnais with a greatly reduced thickness. From a boring just made at Montalaire, 2 miles inland from Boulogne, it may be inferred to be there at least 364 feet

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M. E. Rigaux's "Notice Stratigraphique sur le Bas Boulonnais" (Bulletin No. 4, année 1865 de la Société Académique de Boulogne), and Mr. Topley's Paper before cited, and that "On the Lower Cretaceous Beds of the Bas Boulonnais' (Quart. Journ. Geol. Soc., vol. xxiv., p. 472); see also the large geological map of the Boulonnais, by M. de Souich.

[1] "Guide du sondeur." Par MM. Degoussé et Laurent. 2nd edit. Vol. ii., p. 484.

thick, while in the neighbourhood of Marquise it is reduced to about 230 feet or 240 feet.[1] On the English coast it forms the cliffs at Kimmeridge in the Isle of Purbeck, where it is not less than 550 feet thick. It then passes eastward, and is lost under the Cretaceous rocks. There is reason to believe, however, that, as it exists in the Boulonnais and reappears from under the Cretaceous series in Bedfordshire and Buckinghamshire, it passes underneath the Wealden area.[2]

In the Boulonnais, the general dip of the Kimmeridge clay is southward under the Cretaceous series, and westward under the Channel, across half of which on the French side it probably extends; for midway between the two coasts is the Varne Shoal, which, from trials made by M. Thomé de Gamond, is formed, there is little doubt, of the hard concretionary blocks of sandstone, characteristic of the Portland series at Gris-nez and Mont Lambert. This shoal probably marks the boundary of the Kimmeridge clay, which there passes with these overlying Portland beds under the Weald clay, specimens of which latter are stated by M. Thomé de Gamond to have been brought up by him between the Varne and the English coast, in depths of 16 fathoms.

The Kimmeridge clay in the Boulonnais consists essentially of massive clays, indurated marls, and thin-bedded argillaceous limestones, with one subordinate central bed of sands and sandstone 12 to 15 feet thick. As a whole this series is impermeable, but still the sandstone and limestone bands give rise to small springs. In the Pays de Bray, three unimportant water levels were found in it. At Sotteville, near Rouen, a strong brine spring was met with at a depth of 670 feet.

It is possible, therefore, that if a tunnel were driven into the upper clays at Andrecelles, between Boulogne and Gris-nez, or else in the lower beds near Boulogne, it might, by following the dip seaward of the Kimmeridge clay, be carried in that formation half-way across the Channel; but the presence of the Portland beds in mid-channel, and of the Weald clay further on, must there give

[1] M. Thomé de Gamond makes it 183 feet thick at Cape Gris-nez.—Op. cit. p. 23, and Table, pl. III.

[2] The Kimmeridge clay (and some of the underlying secondary strata) may be more or less reduced under the Wealden area. For, as mentioned above, the superposition of the Wealden on those strata, shows, in the Boulonnais, a considerable amount of preliminary denudation; so that, looking at the much greater volume and depth of the Wealden in the English area, it is possible that it may have been deposited in a channel or basin denuded partly out of the Portland, Kimmeridge and Oolitic strata, and that a portion of these formations may be removed from under the Wealden area.

rise to one of two conditions of structure. It may be supposed either that the Kimmeridge clay dips thence to Hythe and passes intact, together with the Portland beds, under the several divisions of the Wealden, of which the uppermost there comes to the surface; or else, from the unconformable superposition of the Wealden to the Jurassic strata apparent in the Boulonnais, and the great development of the Wealden strata in Kent, it may be supposed the Portland beds and some of the Kimmeridge clay are denuded and replaced by Wealden strata. In the former case, the tunnel would have to follow in the line of the Kimmeridge clay across the Channel, and to be brought to the surface through the Portland and Kimmeridge clay beds, succeeded by one or all of the divisions of the Wealden,[1] according as they may or may not have thinned out against the Palæozoic ridge. In the other case (Section 5, Plate 2), the Portland beds would be gradually replaced on the same level by some member of the Wealden, possibly the Upper Weald clay,—like the Permian beds overlap the scarped edges or slope of the Coal Measures, on the east side of the Coalbrookdale coalfield,—so that a tunnel would pass directly from the one impermeable stratum, to another equally or more impermeable, and in such a case the work might not be impracticable.

Between Boulogne and Ambleteuse the strata are considerably disturbed.

The Oolites.—The freestone and rubble beds, whether of the Coral Rag[2] or of the Great Oolite, are too permeable, while the Oxford clay, lying deeper, and being therefore more inaccessible than the Kimmeridge clay, presents in consequence greater difficulties. They outcrop 3 miles eastward of Boulogne, near which town their thickness has recently been proved, by a well-boring, to be 425 feet. These are the lowest members of the Secondary series, which are known to exist in the Boulonnais. M. Thomé de Gamond introduces the Lias, but it is not known that that formation ranges so far to the north-west of France. Its last appearance is in the Department of the Ardennes. The Sub-Wealden boring

[1] The prolongation of the Palæozoic axis of old rocks of the Boulonnais under our Wealden area, renders the presence and the thickness not only of the Jurassic but also of the Wealden strata at Hythe very uncertain. The upper and lower division of the Wealden need present no difficulties, but if the Hastings sands extend there in any importance, they would offer serious obstacles to the passage of a tunnel in its ascent to the surface.

[2] The Coral Rag containing some argillaceous beds, might not, for a short distance, present any insuperable difficulties, but the Great Oolite, and associated beds, would doubtlessly be perfectly impassable. A very large quantity of water was given out by the lower beds of the latter at the Montalaire boring.

now making near Battle will throw important light upon the succession of the Jurassic strata under the Wealden.

It may be remarked that, a few years since, it was proposed to make a tunnel commencing on the French side of the Channel in the Great Oolite near Marquise, emerging from which it would enter the Oxford clay, and so pass on in succession through the Coral Rag, Kimmeridge clay, Portland Sands, Wealden strata, and issue on the English side through the Lower Greensands, thus intersecting all the Lower Cretaceous and the Jurassic strata, regardless of their lithological structure. The proceeding is of so bold a nature, that it is hard to imagine that the energetic author of it could have been aware of the difficulty, and, in some cases, the impracticability, of carrying merely vertical shafts beneath the line of water-level through some of these strata.

The Palæozoic Series.—Thus far all the strata have followed in a regular order of succession, underlying and cropping out from beneath one another in consecutive order. But this regularity suffers a remarkable interruption on a line running in an E.S.E. and W.N.W. direction, passing immediately north of the Boulonnais. There the Lower Greensand, Wealden strata, and the Jurassic series, instead of being prolonged northward under the Chalk, are interrupted in their course, and thin out against a ridge of older rocks, which, with the exception of a slight exposition above ground in the Haut Boulonnais, runs underground from Belgium to the south-west of England, only the Chalk and Gault passing northward on to and over the crest of this underground ridge (Sections, Plate 9).

This ridge is part of a great range extending from Westphalia to the south of Ireland, and forming a tract about 800 miles in length, with a breadth varying from 20 miles to 60 miles, whilst the main ridge is subtended to the north by a lower, but still a raised underground tract of the same old rocks (Sections 6 and 7). These form the fundamental rocks or rock floor, over which the Tertiary and Secondary strata are spread in the south-east of England, Belgium, and Northern France. They were raised into mountain chains, possessing a similar definite strike and direction, and into continental areas with intervening seas, before the deposition of any of the Secondary strata, the accumulation of which then commenced in those seas, and gradually spread transgressively over all the Palæozoic rocks as the old continental areas were submerged.

These two sets of rocks are therefore perfectly independent one of the other; and the direction, range, and depth of the under-

lying Palæozoic rocks, could no more be inferred from the bearing of the overlying Secondary rocks, than could the direction and levels of the old Roman roads be known by an inspection of existing railways.

These Palæozoic rocks consist in the Ardennes, where they are best known, of a central axis of Silurian strata, flanked by Devonian rocks, and then by Carboniferous strata. These are contorted and tilted at every possible angle, but the strike is always in one given direction, and they thus form a series of narrow parallel anticlinal ridges and synclinal troughs, having each only a small breadth from north to south, but a great length from east to west. Thus the rich coal basin of Belgium and the north of France consists of about 7,000 feet to 8,000 feet of Coal Measures crushed up into a trough, which is only 3 to 6 miles wide from north to south, but which ranges east and west for a distance of 164 miles. Where these Palæozoic rocks pass beneath the surrounding newer formations, the horizontal beds of the latter repose on the upturned edges of the former. Similar features prevail where they emerge again from beneath the secondary rocks in the west of England.

With regard to that portion of this great axis which passes underground beneath the Channel, reference has been made to its more distant sections for the purpose of showing how permanent are its characters, and how persistent its range; and that its exhibition in the Boulonnais is not a mere local disturbance, but part of one great and general phenomenon affecting the same class of rocks along a given line over a very wide area. At the same time it is to be remarked that, although the strike of the axis is, as a whole, from east to west, yet it has local deflections, which, for certain distances, give it a direction E.S.E. and W.N.W. This is important to note.

The extent of area of these old rocks in the Boulonnais is small. They emerge at Caffiers and Hardinghen from beneath the Chalk and Gault, and disappear at Marquise and Réty beneath Jurassic strata. They are, as in Belgium, tilted at high angles, and thrown also into a series of anticlinal and synclinal lines. The strike, however, has here a more north-westerly direction than in Belgium. M. du Souich, who has mapped the Palæozoic rocks of the Boulonnais with great accuracy, makes the several bands of Devonian and Carboniferous Limestone, with the associated coal beds, strike persistently W. 30° N. and W. 30° S. over the whole area exposed, which has a length of 5 miles, with a width of $4\frac{1}{2}$ miles. Mr. Godwin-Austen's and the Author's observations confirm this, and also the existence of

a similar line of strike in the small tract of Palæozoic rocks cropping out in the bottom of a chalk valley at Matringhen, 20 miles to the S.E. of this district.

Of the Silurian rocks in this area little is known; they consist of hard quartzites, slates and grits. The Devonian rocks, on the contrary, are well exposed. They consist of alternations of purple and grey shales, schists, and fissile sandstones, with hard compact limestones and dolomites, together, probably, not less than 2,000 feet thick. These are succeeded by the Carboniferous series, composed of fissile sandstones, dolomites, hard compact limestones, with a subordinate series of coal beds, sandstone, and shales, together, possibly, about 2,200 feet to 2,500 feet thick. The true Coal Measures are higher in the series, and pass further to the north.[1] The trough in which they lie thins out between Bethune and Calais, and there is reason to suppose that it sets in again in the neighbourhood of the latter town.

The Palæozoic rocks of the Boulonnais pass on the southward under the Jurassic formations already described. To the north, the Devonian rocks, after passing under the Chalk and Gault in the cutting between Beaulieu and Caffiers, at an elevation of 250 to 300 feet above the sea-level, have been met with again at Hames-Bucres, near Guines, 4 miles further north, under 635 feet of Chalk and 33 feet of Gault; at 10 miles to the north, beneath Calais, at a depth of 1,032 feet under the same strata; and again at Ostend 56 miles distant under 985 feet of similar strata (Sections 2, 3, and 7, Plate 2).

The question now arises what is the trend and depth of the Palæozoic rocks westwards under the Channel? The only place between Calais and the West of England where the Chalk has been traversed and the Palæozoic rocks found beneath them is at Kentish Town, which is situated nearly on the main line of strike of the Palæozoic axis. Red sandstones, probably of Devonian age, were there met with at a depth of 934 feet below the sea-level, and under a thickness of 1,114 feet of Tertiary strata, Chalk, and Gault. At Harwich, which is 80 miles north eastward of Calais, Lower Carboniferous rocks have been proved to lie immediately under the similar strata at a depth of 1,026 feet. It is known from trials made by Sir John Hawkshaw, the particulars of which he has obligingly supplied, that, on the coast about 3 miles westward of Calais, a boring, 551 feet deep, passed through 197 feet of White Chalk

[1] Some of the French geologists now consider that the Hardinghen coalfield is a prolongation of that of Belgium and Valenciennes; but this, so far as the 'massif' of old rocks is concerned, is immaterial to the question.

with flints, and 284 feet of Grey Chalk. Add to this, the 64 feet extra of Lower Chalk existing at Calais, and it will there give to the base of the Chalk a depth of about 615 feet beneath the sea-level, or 410 feet higher than at Calais; on the English coast, another boring Sir John Hawkshaw had made at St. Margaret's Bay—about 4 miles eastward of Dover—after traversing 240 feet of White Chalk and 296 feet of Grey Chalk, reached the Gault at a depth of 554 feet (Appendix, p. 139).

With a persistent trend of so wide a range, and with a strike subject to so little variation, there is reason to believe that the main axis of the Palæozoic rocks, after their exhibition in the Boulonnais, passes under the Channel, and that the crest of the same ridge would probably be found underground somewhere near Folkestone. The elements of greater uncertainty are—1st. The depth at which the older rocks lie; 2nd. The line along which the Wealden and Lower Cretaceous strata thin out against the older rocks.

The Lower Greensand, and the Wealden strata have at Folkestone and Hythe dimensions far in excess of the same beds at Wissant. Still there is some evidence of their thinning out: for, on the western side of the Weald, the Lower Greensand has a thickness of as much as 500 feet, which is diminished to 260 feet at Folkestone. Of the thickness of the Wealden series in the Hythe district there is no positive information. We have assigned to it a thickness of 600 to 800 feet; but there are no borings or wells to give exact measure, and the only guide in this case has been the dip and range of the beds between that town and Appledore—a fallacious guide in a case like this, where the beds are very obscure and where the lower divisions may be affected without the upper or surface beds showing it.

Any estimate, therefore, of the dimensions of the Wealden and Jurassic series under Folkestone must be conjectural. Looking at the tolerably certain range of the Palæozoic rocks westward from the Boulonnais, and the partial thinning out of the Lower Greensand at Folkestone, the Author would be disposed to expect a somewhat like thinning out of the underlying Wealden and Jurassic formations in the English as in the French area; and that further northward, at Dover or St. Margaret's, the Gault may overlie almost directly the Palæozoic rocks.[1] If such should be the case,

[1] Fragments of mica slate have been found in the Lower Chalk near Folkestone. "Mem. Geol. Survey," vol. iv., p. 33. These all tend to show the proximity of an old land surface of Palæozoic rocks. In the Lower Greensand at Maidstone, pebbles (some of large size) of Palæozoic rocks are occasionally found, and in one part of the Wealden series they are not uncommon.

then the boring at St. Margaret's would give about 650 to 700 feet as the depth to those rocks at that spot. (See map, Plate 8, and Section 6, Plate 9.) In the Boulonnais, at a distance of 10 miles south from the exposed older rocks, the Jurassic series have already attained a development of 1,000 to 1,100 feet. If to this is added the thickness of the Wealden and Greensands, there will be an additional 100 feet, making the dimensions of the Secondary rocks 1,100 to 1,200 feet; while in the neighbourhood of Marquise it seems probable that they do not attain much more than half those dimensions. Again, as the Palæozoic rocks are not less than 750 feet below the sea-level at Boulogne, and as they rise to a height of 378 feet above the sea beyond Marquise, the difference of level exceeds 1,100 feet in these 10 miles; so if the main axis of the Palæozoic rocks underlies the Gault at Dover and has a similar slope southward, the older rocks might be 1,600 feet deep at Hythe; but if the axis maintains the direction it has in the Boulonnais it must pass under the Greensand near Folkestone, and the older rocks may then be more than 600 feet to 800 feet deep at Hythe. The Author has, in the sections, taken as a possible approximation the depth at Hythe to be about 800 feet, and at Folkestone 300 to 400 feet. (Sections 4, 5, and 6, Plate 9.)

Assuming hypothetically these conditions of range and depth of the Palæozoic rocks, we will now examine the lithological structure of their several divisions with reference to their water-bearing characters—first, where exposed on the surface, and then when covered by newer rocks.

With regard to the Silurian and Devonian series, M. Laurent[1] states that rocks of this age rarely contain any levels of water, and that it is only encountered in fissures. The Silurian strata in this area are not exposed. They are generally impermeable.

The Devonian series is largely developed, and contains a large proportion of impermeable schists and shales. The railway section between Caffiers and Beaulieu cuts through Lower Devonian strata, dipping at an angle of 27° to 32° southward, and measuring about 2,000 feet across their outcropping edges. In this distance there occur about 70 feet of fissile and compact sandstones, and solid limestone, and 380 feet of impermeable schists and shales, while about 1,300 feet of sloped surfaces probably indicates the presence of soft strata,—such as shales. Higher in the series are thick beds of compact limestones and dolomites, possibly 500 feet to 600 feet thick, the whole capped with by 200 feet to 300 feet more of impermeable grey and purple shales.

[1] Op. cit., p. 333.

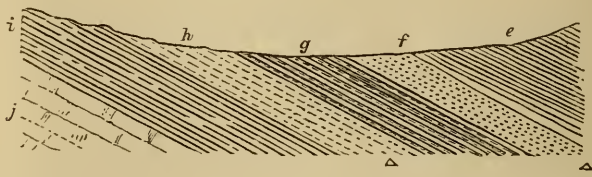
The Mountain Limestone series, which next succeeds, consists of compact limestones with subordinate dolomites, and with an intercalated series of coal strata, formed, as usual, of alternating beds of permeable sandstones and impermeable shales, altogether probably 2,200 feet to 2,500 feet, or more, thick. As these crop out at a high angle, and the surface is traversed by several small streams, the permeable beds of the coal series give admission to much water, the transmission of which is, however, localised by the large faults which traverse the measures. The coal mines at Hardinghen, which are worked in these beds, suffer so much from water, that it was a question, a few years since, whether they would not have to be abandoned in consequence. The water is now kept under by powerful engines.

The great limestone bands of the Carboniferous series, as well as those of the underlying Devonian series, also hold large quantities of water in their fissures and cavities, when they are below the line of water-level, and their surfaces are exposed.

The conditions, however, that obtain when these rocks pass under great masses of superincumbent strata are extremely different.

Permeable strata, *f*, *h*, Fig. 1, cropping out on an exposed surface, or exposed in the bed of a stream, or in the sea channel, serve, as is well known, as vehicles to conduct the rain, river or sea-water underground along the line of their passage, the current being kept in defined bounds by the impermeable strata *e*, *g*, *i*; and any works executed at Δ on the prolongation of *f*, *h* must be subject

Fig. 1.



to the drainage of the whole section of *f* or *h* above those points. A fault throwing *f* against *e*, or *h* against *g*, might serve to stop the transit of the water, but its effect would be uncertain, and would depend on the relative dimensions of *f* and *h*, to *e* and *g*.

The section Fig. 1 may, in fact, be taken as representing the outcrop of the Portland Sands *f* from beneath the Wealden *e*, and of the Coral Rag *h* from beneath the Kimmeridge clay *g*, while from beneath the Oxford clay *i*, the Great Oolite *j* crops out. With such a structure, the influx of the surface waters into the Oolites along their line of outcrop near Marquise, and of the sea-water into the

Portland Sands, and other permeable strata at their outcrop in the Channel is inevitable. As the tunnel before referred to was to pass first through the Great Oolite from its outcrop to near Gris-nez, then through the overlying beds, as they are brought by their dip to the level of the tunnel, to the Portland beds at the Varne, from which it would pass to the Weald clay and into the Lower Greensands on the English coast, there can be no doubt that any such attempt would have proved futile, owing to the unavoidably great influx of water both from the land and from the sea. It is true it did not escape the notice of the projector that these several strata are water-bearing, but he does not seem to have attached sufficient importance to the difference between the water discharge in that portion of the strata above the level of the permanent water line, which only deals with the annual rainfall and surplus quantities, and the formidable underground reservoirs constantly stored in such strata below that line; nor to the fact, that although the sea-water may not infiltrate in a vertical line, it would follow the oblique line of bedding, however long, whenever the strata crop out in the bed of the Channel.

It is this which constitutes the great danger in dealing with the Secondary strata under the Channel, where these conditions prevail. It is an imminent risk, even should it be desired to keep the work within the impermeable beds only. If the dips of these strata were uniform, and it were certain that no faults existed, then a tunnel might be carried with safety in the centre of an impermeable deposit, by adopting, if possible, a gradient coincident with the angle of outcrop; but although the dip of the strata may have on the whole a general and given direction to a certain point or line, it is liable to constant minor variations and accidents. It is only requisite to look at the coast sections, to see how common faults are. Small ones would be unimportant, but larger ones might offer serious obstacles, less only in proportion as the strata are thicker. This must be taken into consideration, and allowed for in all preceding observations on the Tertiary and Secondary strata. It is a qualification important to bear in mind, not as a certainty, but as a certain contingency. It must also be remembered that these faults must all pass through the underlying Palæozoic strata, which suffer in addition from other faults of older date,[1] but the mass of these rocks is so great, that the faults are of less importance, especially on the line of strike.

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[1] The old faults of the Palæozoic series were all levelled and planed down before the deposition of the Secondary strata.

With respect to the Palæozoic formations, where they are overlain by newer formations, other conditions come into play than those of outcrop and permeability—conditions by which, whatever may be the permeability of certain strata, its consequences are generally nullified and rendered inoperative. This gives to these rocks in such cases a peculiar value for submarine work.

The Palæozoic strata of this part of Europe were, as before mentioned, upraised, contorted, and formed into continental areas at the end of the Permian period, and consequently all the Secondary strata which were subsequently deposited, overlie the former unconformably, and in masses in accordance with the depth of the sea basins intersecting these old continental areas, and their thickness increases with the distance from the old shores; whilst over the continents themselves, either the Secondary strata were not deposited, or only such members of them as were formed at a later period when those continents were submerged.

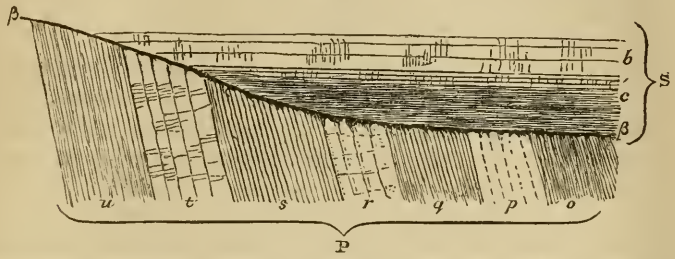
In this way the Silurian, Devonian, and Carboniferous strata, forming the Ardennes, and stretching from Central Europe to the south-west of England, were first squeezed and elevated into their numerous parallel anticlinal and synclinal lines; and then, whilst the central raised tract, or, at all events, the higher portions of it, remained above water during all the earlier Secondary period, certain portions to the south of the main axis were gradually submerged; and finally the lower parts of the main axis, and the tract to the north of it, were also submerged.

Thus to the south of the Palæozoic area in the Boulonnais, the Jurassic and Wealden strata are largely developed, but they thin off against this axis of old rocks; while the crest of the Palæozoic ridge, and the tract immediately north of it, are covered only by the Gault and Chalk. In the same way the Palæozoic rocks of Belgium are covered only by Cretaceous and Tertiary strata, whilst as they trend and deepen southward into France, all the Oolitic series gradually set in over them, showing the original existence of a depressed area to the south of the old Palæozoic ridge.

It follows from this, that the Secondary strata S were spread gradually and transgressively over the upturned and denuded edges of the older rocks P, as shown in Fig. 2; and therefore the actual water-bearing condition of these Palæozoic rocks depends on the characters of *c*, *b*. If the Palæozoic rocks P contain permeable strata, their action would depend not upon their own lithological structure, but rather on that of the over-lying Secondary strata; for if S is formed of impermeable strata, they would effectually prevent the influx of rain, river, or sea water into P.

In Fig. 2 let p, r, and t represent the more or less permeable strata of the Palæozoic rocks P, and c an impermeable deposit of the Secondary formations S. Here the outcropping edges of p r are

FIG. 2.



efficiently protected by the overlying strata c, while laterally r p are protected by their associated beds o, q, s, and although t is exposed to communication with b, that communication is restricted in its operation by causes next to be mentioned. Supposing b to represent highly aquiferous strata, or a body of water whatsoever, no water could pass from it into p or r.

In addition to these circumstances, the action first—of the air, during the exposure of the old Palæozoic surface β, β, led to the decomposition of the surface of the rocks, converting the shales and schists into clays,—and subsequently the action of the water when the tract was submerged caused these argillaceous materials to become mixed with the first sedimentary deposit, and washing this basement bed into all the irregularities of the surface, and filling all its fissures, puddled as it were with a liquid grouting the edges of the old rocks, and still more effectually prevented communication from the overlying deposits.

The Author has dwelt thus long on these points because he believes they offer a solution to the problem of driving a tunnel safe from the irruption of water under the Channel. In the tract between the Boulonnais and Calais, the conditions just described especially prevail, as the Palæozoic rocks on the northern border of the Boulonnais axis are directly overlain by the Gault clay, succeeded by the great mass of Chalk Marl—an order of superposition which has been shown to be continued to Calais and Ostend, and most probably extends westward across the Channel. Neither in the borings at the towns last named, nor in the analogous ones at Kentish Town and Harwich, was any water found in the underlying older rocks. The same remark applies to the numerous borings for coal in the district between the Boulonnais and Bethune, where the Devonian or the Silurian rocks were met with.

There is, however, an important exception to this rule. At Lille and Roubaix, Artesian wells have been carried successfully through the Lower Chalk into the Mountain Limestone, and in the fissures of the latter large quantities of water were at once found which rose to the surface; but M. Laurent[1] considers these to be exceptional cases, due to local causes.

But besides these instances relating to shafts and borings, to which, as beforesaid, some uncertainty always attaches, other evidence enables a judgment to be formed with much greater certainty of the extent to which Palæozoic strata, more permeable than the Devonian, can actually be worked under highly aquiferous deposits, of a depth exceeding the depth of the Channel, and at a level even lower than that at which the Palæozoic strata lie at Calais.

In the great coal basin of Mons, the Coal Measures are covered by variable and often great masses of Tertiary and Upper Secondary strata, some beds of which are impermeable, whilst others, on the contrary, are extremely permeable and full of water. These overlying strata are from 100 feet to 1,200 feet thick; and as the surface of the ground does not average more than 200 to 300 feet above the sea level, the top of the Coal Measures is in places as much as 900 to 1,000 feet below that level. In no part of the Channel under consideration does the depth exceed 186 feet, and it rarely is more than 150 feet.[2]

The Lower Tertiary strata of Belgium (the Laudenian Sands) consist of light greenish sands, forming beds about 100 feet thick. When below the water line of the country, the sands contain so much water that they are like a quicksand. The Upper Chalk, which attains in places a thickness of 1,000 feet, is very friable and broken, and its fissures are everywhere full of water, so that

[1] Op. cit., vol. ii., p. 380.

[2] The height of the river at Mons, above the sea level, is 102 feet, and the general height of the country, which is slightly undulating, may be 200 feet to 300 feet more. The depth which the Thalweg of the basin of Cretaceous and Tertiary strata, filling the depression in the Coal Measures, attains in various parts of its course, will show the importance of this overlying mass of more or less aquiferous strata, and the great depth at which the Coal Measures are worked under them.

Approximate depths of the Thalweg below the level of the sea at the various places here named.

	feet.
St. Vaast	331
Near Nimy	1,033
South of Ghlin	721
Douvrain	787
Pommerœul	1,040
South of Harchies	820

See Cornet and Briart's "Terrain Crétacé de la Province de Hainaut."—Mons, 1866, p. 6.

extreme difficulty is experienced in sinking shafts through it. Under these beds is the Lower Chalk, or Chalk Marl, which is from 30 feet to 250 feet thick, and comparatively impermeable; and at the base of it is a thin, compact conglomerate, called Tourtia. Beneath these are 60 feet to 600 feet of Greensand (Meule de Bracquegnies), and then 20 feet to 500 feet of the Aachenian beds. These two latter formations present difficulties even more formidable than the Upper Chalk. The sands of both are so loose and moveable, and the pressure of water at the great depth at which they lie is so great, that in many districts it was, until lately, found to be impossible to sink shafts through them.

Nevertheless, notwithstanding the great volume of water held in these beds, the Coal Measures underneath are comparatively dry.

M. Cornet and M. Briart, Civil Engineers, and managers of some of the largest works in the Hainaut Coalfield, state, in a communication to the Author, that as the result of their experience, it is only when the Tertiary sands, the lower Greensand and the Aachenian sands repose directly on the Coal Measures that these are invaded by water; and M. Briart says, "that in this case it is generally in those works which cut across the strata, or, in fact, work at right angles to the strike; but that when they follow the vein the mine is generally dry. In any case, it is excessively rare that the water in the coal mines offers any serious obstruction to their working. It is only when the works approach too near to the water-bearing strata that irruptions of water occur." M. Cornet writes, "that when the works are conducted with prudence, they can approach very near to the Cretaceous strata. In one case coal seams are worked at from 30 mètres to 40 mètres beneath those strata in places where the latter were 250 mètres thick, and contained a body of water 220 mètres high."

M. Cornet concludes by stating, that "when the Coal Measures are covered by the Chalk Marl (Dièves), which is generally the case, they are found altogether free from water coming in from the overlying strata. Just now, at a depth of 25 mètres in the Coal Measures at Maurage (see p. 132), there is no water. In those places where the Coal Measures are covered by the Greensands and the Aachenian sands water sometimes passes; but more commonly none passes, for the shales are altered, and converted into a sort of clay (which stops the water). Sometimes, however, when the Tertiary sands directly cover the coal strata, much water passes when the works come near to them. Nevertheless, I am of opinion, and experience proves that I am right, that they can always mine under great thicknesses of water (water-bearing

strata), without its penetrating into the works. At the Grand Hornu, near Mons, they are at present working under 300 mètres of water, at a distance only of 40 mètres from the base of the Morts-terrains (unproductive overlying strata)." [1]

Mr. Warrington Smyth, also, in a Paper communicated to the North of England Mining Institute,[2] remarks that "the northern coalfield of France is covered by Cretaceous strata, which, down to 100 yards or 120 yards deep, are some of the most troublesome a miner can meet with." Of the beds overlying the Belgian coalfield he says, they "consist in great part of sands, marl, and Chalk, with occasional bands of massive flints and loose or running sand, and with water extremely abundant;" and he alludes to several failures in sinking shafts, in consequence of the difficulties thus presented, until the new method of sinking in water was introduced by Messrs. Kind and Chaudron.

Mr. Smyth goes on to observe, after speaking of the difficulties of passing through the overlying beds, that when "the excavations reach certain of the more solid lower beds of the Cretaceous series, the so-called Dièves or the Tourtia, or have penetrated to the Coal Measures themselves, scarcely any addition to the water is expected."

Applying these considerations to the Palæozoic rocks as they pass under the Channel to England, it is evident, from the great dimen-

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[1] Some of the other particulars given by these gentlemen are too pertinent to the subject to be omitted. The following are extracts from M. Briart's communication:—

"The strata most charged with water are—

"1. The Lower Tertiary sands of the east of Hainaut.

"2. The thick mass of the White Chalk.

"3. The bed of sandy chalk marl with large irregular concretions of flint.

"4. The Greensand of Bracquegnies.

"5. The sands of the Aachenian system.

"The quantity of water in these beds is often very considerable. It is the flinty bed, No. 3, called Rabots, which contains most. With respect to the Aachenian sands, they may be said to be impregnated with it, and it is useless to think of passing through any thickness of them by the ordinary methods of sinking. In sinking through the White Chalk and the rabots, the discharge of water in bad cases amounts to from 4,000 to 6,000 cubic mètres in 24 hours, but generally it does not exceed 1,500 to 3,000 cubic mètres. In one instance, in a pit at the Couchant du Flénu, the discharge amounted to 12,240 cubic mètres.

"The White Chalk and the rabots are never in direct contact with the Chalk. They are generally separated from it by other beds more or less argillaceous and impermeable (Fortes-toises, Dièves), which act as a barrier between the water held in the water-bearing strata and the underground works, so that these workings

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[2] *Vide* Transactions of the Inst., vol. xx., pp. 196 and 189.

sions and general impermeability of these strata, their persistent rectilinear strike,—and their security against the influx of water, in consequence of the continuous overlie of the impermeable Gault and of the Chalk Marl,—that these old rocks are likely to offer the surest and safest means of submarine communication

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can be extended beneath the aquiferous beds without meeting any large quantity of water, and requiring only a comparatively restricted drainage.

"But it is different when the tertiary sands which lie on the east of the basin, or the Greensands and Aachenian sands which occur on its northern edge, repose directly on the Coal Measures. In those cases the beds of sandstone intercalated in the Coal Measures, and which are always more or less fissured, allow readily the influx of the water from the overlying strata (*morts-terrains*). The pits, when the use of powerful engines is much required, are mostly those which work across the beds (*à travers-bancs*), or across the strike of the strata. The works, on the contrary, which follow the vein (or along the strike) rarely yield any water, except where there is a bed of sandstone in close proximity, or a fault intervenes."

M. Cornet gives the following particulars of the strata in descending order :—

"Chalk A.—White Chalk, generally greatly fissured, and giving much water. Thickness, 0 to 346 mètres.

"Chalk B.—Rabots. This is a bed formed of numerous seams of massive and single flints in a grey chalk. It is fissured, and gives a great quantity of water. Thickness, 3 to 40 mètres.

"Chalk C.—Chalk Marl. More or less argillaceous, and containing in its upper part siliceous concretions. It bears the name of *Fortes-toises* when it contains these concretions. The lower beds are simply a very clayey marl, to which is given the name of *Dièves*. At the bottom is a thin bed of green chloritic marl, with pebbles called *Tourtia*. The division C is impermeable, and prevents the waters of A and B descending lower. On the south of the basin it is only 7 to 10 mètres thick; but on the north it is sometimes as much as 80 to 100 mètres thick.

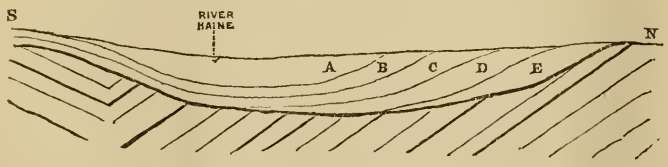
"Greensand D.—A greenish sandstone, very hard and very much fissured, containing much water. Thickness, 20 to 180 mètres.

"Aachenian Strata E.—An irregular series of sandstones, pebble-beds, sands and clays, with lignites. They contain much water, and the sands which are there met with are shifting sands. Thickness, 5 to 150 mètres.

"The formations D and E exist only on the northern side of the coal basin."

He illustrates the range of these beds by the following section, Fig. 3.

Fig. 3.—Section across the Hainaut Coalfield.



M. Cornet then proceeds to give some special and extreme cases of the discharge of water in strata overlying the Coal Measures, in sinking certain pits near Mons.

between the two countries; but as distance seems an insurmountable objection in the case of the London clay, so depth may here also render the other conditions nugatory. If the trend of the Carboniferous rocks were followed from near Calais (Section 2,

	1. Pit at Quaregnon.	2. Pit at Harmignies.	3. Pit at Couchant du Flénu.
	Mètres.	Mètres.	Mètres.
Drift beds	4·5	6·20	4·5
Tertiary sands . . .	·0	7·80	13·1
Strata A	17·3	117·50	108·3
„ B	3·	5·35	4·7
„ C	6·	3·15	10·
	30·8	140·	140·6

Pit 1. Water stood at 1·5 m. from surface; discharge in B 22,000 cubic mètres per 24 hours.

„ 2. Water stood at 53 m. from surface; discharge in B 7,000 cubic mètres per 24 hours.

„ 3. Water stood at 18 m. from surface; maximum discharge 11,000 cubic mètres per 24 hours.

"The discharge of A is not given in 1 and 2. It is merely stated to be very large.

"The quantity of water in the aquiferous strata, where they were thicker, is so great, that in places it was impossible to sink through them until the introduction of the system *Kind-Chaudron*. By means of this machinery they have now succeeded in sinking through very great depths of this water-logged strata. The following are the most remarkable and successful instances in places where all ordinary means had failed:—

	1. Pit at Maurage.	2. Pit at Harré.[1]	3. Pit at Bracquegnies.
	Mètres.	Mètres.	Mètres.
Drift beds	3·64	14·20	11·50
Tertiary sands . . .	3·18	·0	1·0
Strata A	117·0	126·98	·0
„ B	30·30	60·52	15·23
„ C	39·71	63·09	19·
„ E	·0	·0	20·17[2]
	193·83	214·89	66·90

"In pit 1 the water stood at 35 mètres from the surface.

" „ 2 „ „ 2 mètres „

„ 3 the pressure in the lower part of E was equal to 35 mètres of water.

"There are pits in this district in which the coal is worked at depths of 610 mètres, 730 mètres, and 800 mètres below the level of the sea."

[1] Not yet finished. [2] Complete quicksands.

Plate 9), the line would probably reach our coast somewhere between the South Foreland and Ramsgate; but the depth would be not less than 1,000 feet to 1,100 feet. If, on the other hand, the prolongation of the Devonian rocks were followed (Section 3, Plate 9) from Guines or Sangatte to the neighbourhood of Dover, they may possibly be found to range at a depth of from 700 feet to 800 feet; or if the Lower Carboniferous or the Devonian rocks could be followed from their outcrop at Leulinghen and Rocthun, near Marquise, they might probably be found to pass under somewhere near Folkestone, at a depth of 300 feet to 400 feet.[1] But in all these cases it must not be forgotten that although the estimates of depth on the French side are tolerably certain, their correctness has to be proved on the English side. They are merely offered as tentative and approximate, and require confirmation by trials, which could, however, be made without much difficulty.

Nor is evidence wanting of the possibility of carrying galleries in Palæozoic strata under the sea, and of ventilating such galleries to a considerable distance from the shafts. On the Durham coast coal pits are worked several hundred yards under the sea, and at great depths; and on the Cumberland coast Mr. G. B. Forster, who drew up the Report on the Coals of the Northern Counties for the Royal Commission, informs the Author that "At Whitehaven we have workings under the sea which are at a distance of nearly 4 miles from the shaft. They are about 2 miles from low water mark, but, of course, under the same conditions as to ventilation as if they had been driven directly seawards. In these workings we have no difficulty with the ventilation, though only produced by a furnace of moderate size. It is intended to put a powerful fan on this pit, and we then expect to carry the workings much further on. These workings are about 200 yards below the sea. All the water met with is salt; but there has been no indication of the sea making a breach, even where the cover is only half that thickness." And, in further explanation, Mr. Forster adds:—

"1. The depth of the sea at the point to which the coal workings are carried is 60 feet.

"2. The Coal Measures (at Whitehaven) are *not* covered by any newer rocks or by boulder clay where they pass under the sea.

"3. The *least* distance between the bed of the sea and the working galleries is 180 feet.

[1] A trial boring recently made near the coast, about 2 miles south of Wissant, ended in Jurassic strata at a depth of about 200 feet, but the Author could not obtain exact particulars.

"4. The shaft is within a few yards of the beach, and the workings actually extend nearly 4 miles under the sea. They are, however, not driven at right angles to the line of coast, and therefore at the extremity they are little more than 2 miles beyond high water mark. There is no communication with the surface except the main shafts, so that the workings are, in this respect, in the same position as if they had been driven nearly 4 miles right out to sea."

It is evident, therefore, that it is quite possible to work the Coal Measures in safety, both under the sea at places where they are dependent only upon the protection afforded by intercalated impermeable strata and by faults, and also under great masses of strata charged with water, from which they are protected by intervening and unconformable overlying formations. It should be noted, also, that in all these cases the works are carried on as usual in open galleries, without the protection of brickwork. If the Coal Measures, with their subordinate permeable sandstones, can be so worked, it follows, with little doubt, that the other Palæozoic strata, which consist of more entirely impermeable rocks, and which are under the same conditions of dip, strike, and overlie, may be expected to offer conditions equally, or even more favourable, for similar submarine work. Briefly to resume :—

In the London clay there exists a perfectly impermeable bed of sufficient thickness, but nowhere continuous between the two countries, except probably at points where the distance presents apparently insuperable difficulties. The Lower Chalk or Chalk Marl affords a comparatively impermeable deposit, also of sufficient dimensions; but from its having a calcareous base, and from the possibility of fissures, with the absence of a protecting overlie, it has great uncertainty. In the Gault there is another impermeable stratum, but of dimensions too small. The Lower Greensand contains no beds sufficiently continuous and impermeable. The Weald clay ranges about half-way across the Channel; and if a belt of it should possibly pass round at the north end of the Varne and range to Wissant, it might prove to be worth further inquiries. In the Kimmeridge clay there is again a deposit of sufficient dimensions, but with subordinate bands which may be sufficiently permeable to present difficulties, whilst, though it comes to the surface on the French coast, its depth on the English coast must be very considerable. There is, however, just a chance that the Kimmeridge clay may in mid-channel be overlapped unconformably, and at a slight angle, by the Weald clay, and in that case they might for all purposes be considered as continuous strata. The

Oxford clay presents similar difficulties, in addition to its greater depth and inaccessibility. In the Secondary strata the irregular lie of the strata, and the presence of faults, are contingencies important to be considered.

On the other hand, the great mass of the Palæozoic rocks so protected by impermeable overlying strata is of such great dimensions, and so compact, and holds its range so independently of the more irregular range of the Secondary strata, that it offers the conditions most favourable for the secure construction of a submarine tunnel; and that such strata can be worked in safety, and for considerable distances, under great bodies of water, has been proved at Whitehaven and Mons. But, on the other hand, the depth of these old rocks below the surface is very great, and they are much more dense and harder than the overlying formations.

There is another important problem in connection with the Palæozoic rocks which such an undertaking might help to solve. The great question of the range of the Coal Measures under the South of England has lately come prominently into notice; and it was, in fact, in inquiries connected with that question that the foregoing considerations presented themselves to the Author. The rich coal basin of Mons and the North of France has been traced to within 30 miles of Calais, where it thins out; but, like the coal basins of Liege, Aix, and Westphalia, which form separate sections of the same great trough, to the eastward, so there is reason to suppose that other sections of the trough set in on the westward, forming other coal basins, which possibly range to the west of England (Somersetshire), passing under the north-eastern part of Kent and the Thames. Any such work, therefore, as a submarine tunnel in these Palæozoic rocks could not fail to throw much light on the subject; while, in case it were to hit upon the line of strike of the Coal Measures, and could be carried on along that line, the work might prove otherwise remunerative, and tend to solve the great problem which interests so largely both geologists and the general public.

Such, briefly, are the conditions which bear on the construction of a submarine tunnel between France and England. The Author is satisfied that, considered on geological grounds alone, it is in one case perfectly practicable, and in one or two others it is possibly so; but there are other considerations besides those of a geological nature, and whether or not they admit of so favourable a solution is questionable. In any case, the Author would suggest that, the one favourable solution admitted, it may be desirable, in a question

involving so many and such great interests, not to accept an adverse verdict without giving all those other considerations the attention and deliberation which the importance of the subject deserves.

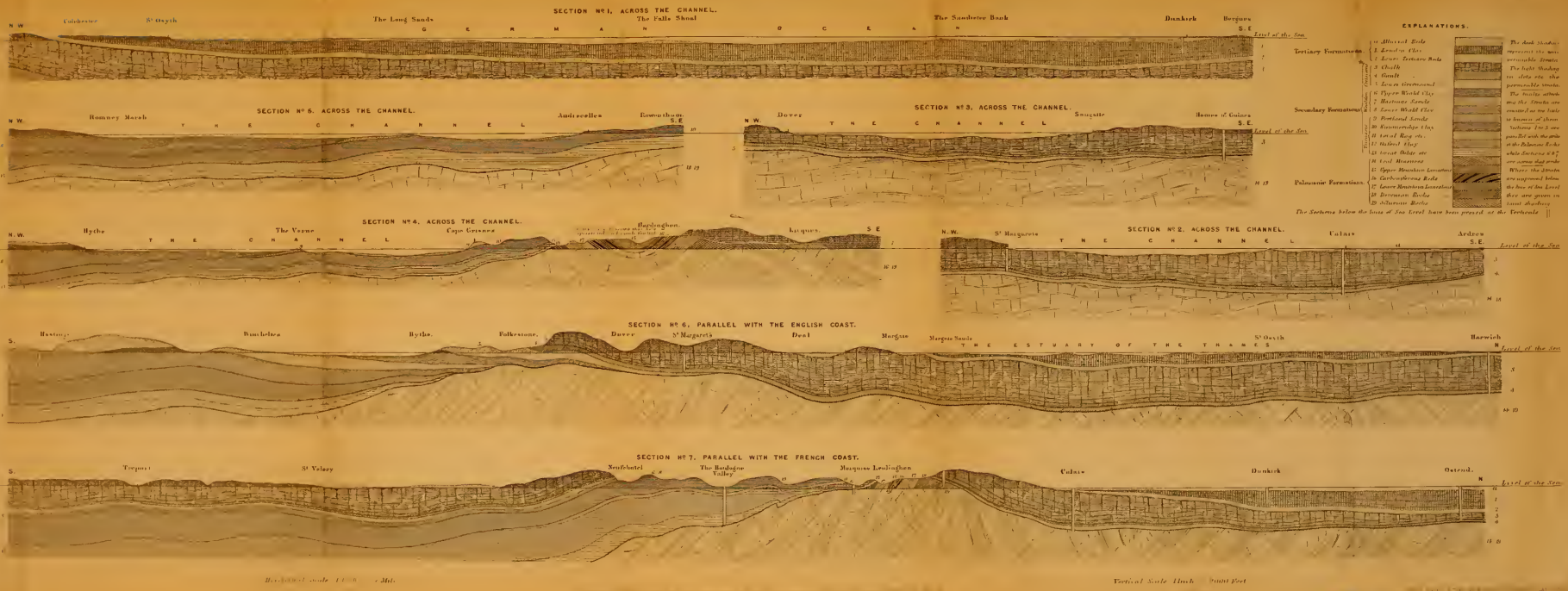
Under any circumstances, the difficulties are formidable. Whether or not they are insuperable are questions which may safely be left to Civil Engineers. The many and great obstacles overcome by engineering science in late years lead the Author to expect that, should the occasion arise, and the attempt be considered worth the cost, the ability to carry it out would not be wanting. Various preliminary trials are, however, indispensable, in order to clear up some of the geological questions before a balance of the comparative advantages presented by the different formations could be satisfactorily settled, and before the grounds for action could be accepted.

The Paper is illustrated by a series of coloured maps and sections, from which Plates 8 and 9 have been compiled and reduced.

THOS KELL LITH 40 KING ST COVENT GARDEN

CHANNEL TUNNEL.

DIAGRAM SECTIONS TO ILLUSTRATE THE PROBABLE GEOLOGICAL STRUCTURE UNDER THE CHANNEL BETWEEN THE SOUTH-EAST OF ENGLAND AND NORTH-WEST OF FRANCE



APPENDIX.

Particulars of Sections giving details of the several formations referred to in the foregoing pages. The right hand column is in most cases added by the Author.

The London Clay and Lower Tertiary Beds.[1]

SHEERNESS.—Artesian Well.

(Abridged from Mr. Whitaker's "Geology of the London Basin" in the "Memoirs of the Geological Survey," vol. iv., p. 468.)

	Feet.	
Clay	9	Alluvial beds.
Shingle	3	
Black mud	35	
London clay, with beds of Septaria in the lower part	293	Tertiary strata.
Loam and sand full of water	10	
Pebbly beds	1½	
Dark green sand with pebbles	7½	
Black loam	1	
Marl with a seam of lignite	3	
White and brown sands	7½	
Quick green sand	10½	
Hard green sand	3	
Total	384	

SOUTHEND.—Artesian Well.

(Ibid, vol. iv., p. 441.)

	Feet.	
Surface soil	3	
London clay { yellow clay	30	Tertiary strata.
London clay { blue clay	384	
Bored through (in adjacent well) running sand, clay, sand and pebbles	181 (?)	
Chalk	302	
Total	900	

[1] See also the Harwich, Calais, and Ostend Sections, pp. 141, 142, and 144.

FOULNESS ISLAND.—Artesian Wells.

(Abridged from Mr. Whitaker's "Geology of the London Basin" in the "Memoirs of the Geological Survey," vol. iv., p. 435.)

	Ft.	Ft.	
Soil	3 to 5		Alluvial and drift beds.
Sand and shingle	40 to 60		
London clay	307 to 335		

Water from greenish sand at bottom.

The total depths of the wells vary from 350 ft. to 400 ft.

MERSEA ISLAND.—Artesian Well at Little Wilsborough.

(MSS. of the late Dr. Mitchell.)

London clay and lower tertiary strata to the chalk, about 300 feet.

DUNKIRK.—Boring for Water.

(From Meugy's "Essai de Géologie pratique sur la Flandre Francaise," p. 225.)

	Mètres.	
1. Made soil	6·66	
2. Quicksand	6·66	
3. Sand with shells, and with very thin beds of silt	7·66	
4. Quicksand of a blackish colour	5	Alluvial beds.
5. Yellowish quicksand, with broken shells	5·66	
6. Blackish sand, mixed with shells	4·33	
7. Tenacious clay, with a few small pebbles at a depth of from 314 to 320 feet (not traversed)	80·66	*London clay.*
Total	116·63	

The Chalk.

MARGATE.—Well Shaft and Boring for Water.

(Abridged from Mr. Whitaker's Paper in "Memoirs of the Geological Survey," vol. iv., p. 467.)

	Feet.	
Chalk	31	
Chalk with flints	265	
Chalk without flints	19	*Upper chalk.*
Grey clayey chalk	3	
Beds of grey and marly chalk	56	
Total	374	

ST. MARGARET'S, NEAR DOVER.—Trial Boring.[1]

(Communicated by Sir John Hawkshaw, Past President, Inst. C.E.)

	Feet.	Inches.	
Shingle	9	0	
White chalk	209	0	
Yellow chalk	4	0	*Upper or White Chalk.*
White chalk	4	0	
Fissure (salt water)	3	0	
White chalk	20	0	
Grey chalk	30	0	
White chalk	10	0	
Blue marl	11	0	
Pipe clay	42	0	
Light blue clay	158	0	
Light stone	1	9	
Light clay	1	6	
Stone	1	3	
Clay	2	6	*Lower or Grey Chalk.*
Stone	1	6	
Clay	3	0	
Stone	1	9	
Clay	10	0	
Stone	1	3	
Clay	10	0	
Stone	0	6	
Clay	10	0	
Green sand	3	0	
Gault clay	19	0	
(Boring still in gault clay) Feet	567	0	

Boring on the French Coast, about 3 Miles West from Calais.

(Communicated by Sir John Hawkshaw, Past President, Inst. C.E.)

	Feet.	Inches.	
Loam, light clay, and black peat	3	0	
Grey sand (with water)	48	0	
Grey sand (with black pebbles)	5	0	
Light brown clay	2	0	
Loose gravel	9	0	
Light sand	1	0	
Flints	2	0	
Loose chalk	5	0	
Hard chalk (white) and flints	3	0	*Upper or White Chalk.*
White chalk	189	0	

[1] "Clay" is probably used in this section in the sense of "marl."

	Feet.	Inches.	
Grey chalk	60	0	*Lower or Grey Chalk.*
Soft chalk (a lightish blue colour)	124	0	
Soft chalk (whitish)	2	0	
Soft chalk (dark blue)	41	0	
Soft chalk (lightish and sandy)	20	0	
Hard grey chalk	37	0	
Total	551	0	

The Jurassic and Oolitic Series.

BOULOGNE.—Boring at Montalaire in the Valley of the Liane 2 Miles above Boulogne.

(From particulars given to the Author by M. E. Rigaux, of Boulogne).

	Mètres.	
Detritus fallen down from the side of the hill. At 23 mètres the water flowed up to the superficial level	23·0	
Alternations of marl and calcareous sandstone	10·0	*Lower Kimmeridge Clay.*[1]
Alternations of marl and marly limestone	9·0	
White lithographic marly limestone which is worked for lime at Val St. Martin, near Boulogne	4·65	
Calcareous sandstone with traces of fossils	0·45	*Coral Rag.*
Oolitic limestone with marl. Second water level	5·0	
Calcareous sandstone and sandy marl	4·90	
Clay, the upper part blue, becoming black in going down	13·0	
Beds of limestone and blue marl	3·85	
Clay with foraminifera	0·30	
Hard oolite with fossils	6·60	
Very sandy clay with beds of schistose stone full of pyrites	6·75	*Oxford Clay.*
Clays and limestone, alternating by beds of 1·50 to 2·00 thickness	13·00	
Blue clay and grey marl	9·20	
Hard limestone	3·65	
Clays and marls	16·90	
Limestone	2·00	
Marl	0·90	
Limestone	1·00	
Clay and marls	10·40	
Limestone, 20 per cent. iron	·50	
Clays and marls, full of the characteristic fossils of the upper part of the Lower Oxford Clay	18·10	
Very hard limestone	0·40	
Clays and marls, with the same fossils as before, but scarcer (lower part of Lower Oxford Clay). This and the upper bed are worked for drains and tiles at Le Wast	23·00	

[1] Above this division is a bed of loose sand and sandstone 12 to 15 feet thick, succeeded by a series of dark clays with septaria and calcareous bands.

	Mètres.	
Oolite	2·30	*Cornbrash.*
Marl and white limestone alternating—is probably our Forest marble	5·00	
Oolite. The thickness is greater by half than I (Mr. R.) thought to find it; but some of it probably belongs to fuller's earth	22·00	*Great Oolite.*
Limestone with fossils, not oolitic (fuller's)	3·65	
Oolitic and siliceous limestone	1·70	
Blue marl, with black oolites and limestone	1·35	
Rock	4·00	
	231·25	

"At 228·15 mètres the water rose rapidly and violently, and overflowed the boring;[1] it has since gone down to the ordinary level. At 231·25 mètres the rock (*Palæozoic?*) was very hard; and they tried during seventeen days to get a specimen, but the diameter of the last tubing was too small to allow it. During those attempts they got to 237 mètres. A very small bit was got up and analysed, and was found quite pure limestone, with a faint trace of magnesia and 2 per cent. residuum."

Position of the Palæozoic Strata under the overlying Secondary formations.

KENTISH TOWN, LONDON.—Boring for Water.

(Abstract from a Paper by the Author in "Quarterly Journal of the Geological Society" for February 1856.)

	Feet.	Inches.	
London clay	236	0	Tertiary strata.
Lower tertiary strata	88	6	
Middle chalk	244	6	Cretaceous strata.
Lower chalk and chalk marl	400	3	
Upper greensand	13	9	
Gault	130	6	
Red and grey sandstones	188	6	*Palæozoic strata.*
Total	1302	0	

HARWICH.—Boring for Water.

(Ibid, "Quarterly Journal of the Geological Society," vol. xiv., p. 250.)

	Feet.	
Earth	10	Alluvial beds.
Red gravel	25	
London clay	23	Tertiary strata.
Coarse dark gravel	10	
Plastic clay	7	
Bluish clay with green sand	3½	
Green and red sand	5	
Blue clay	3	

[1] The water rose to 9 m. 54 c. above low water.

	Feet.	
Chalk with flints	690	Cretaceous strata.
Chalk (lower) without flints	160	
Chalk, rocky, in thin layers	38	
Greensand (upper)	22	
Gault	39	
Black slaty rock	44½	*Palæozoic rocks.*
Total	1070	

CALAIS ARTESIAN WELL.—BORING FOR WATER.[1]

(From the "Almanach de la Ville et du Canton de Calais pour 1845," p. 112–13, with additions from letters of Mr. E. Blakewary, and by the Author from inspection of specimens in the Calais Museum.)

	Mètres.	
1. Made soil and gravel	3·00	Alluvial beds.
2. Grey and yellow quicksand, with shells	8·50	
3. Grey and bluish quicksand, with shells and vegetable remains	11·80	
4. Brown sandy clay	0·50	
5. Rolled pebbles with veins of clay (some pebbles being found ·20 c. in diameter)	2·65	
6. Brown clay	6·05	London clay.
7. Sandy clay	0·20	Lower Tertiary strata. (Lower Landinian or Thanet Sands.)
8. Greenish argillaceous sand	0·35	
9. Green sand, with iron pyrites and shells	2·70	
10. Very large rolled pebbles. (These two beds were very slowly traversed. An effort was made for the tube to penetrate with a weight of 900 kilos., but without success)	1·10	
11. Greenish grey sand, with traces of shells	10·00	
12. Very fine grey sand—lighter coloured and shells	5·20	
13. Light brown sandy clay	0·55	
14. Sandy conglomerate, with iron pyrites	0·30	
15. Argillaceous sand, and with shells	1·80	
16. Compact sandy clay, with iron pyrites	3·30	
17. Very compact clay, brown, and with shells	7·00	
18. Hard sandy clay and green sand	2·00	
19. Greenish argillaceous sand	1·10	
20. Argillaceous grey sand	2·20	
21. Brown sandy clay	2·40	
22. Brown clay with flints (*green coated*)	0·25	
23. Friable white chalk	8·05	Upper and middle chalk.
24. White chalk, with a few black flints	83·45	
25. Grey chalk, with cherty flints	4·15	
26. Marly chalk	0·05	
27. Hard chalk (tufaceous), with a few flints	33·25	

[1] This and the preceding two borings were unsuccessful in procuring water.

	Mètres.	
28. Very hard chalk marl	1·40	Lower chalk and chalk marl.
29. Very hard chalk	9·60	
30. Ditto marly chalk	9·40	
31. Grey chalk (*craie siliceuse*), with iron pyrites	2·15	
32. Bluish grey chalk, very hard	1·15	
33. Very hard chalk marl	0·75	
34. Grey chalk (*craie siliceuse*), very hard	4·50	
35. Grey chalk (*craie siliceuse*), with iron pyrites	7·50	
36. Very hard chalk	26·55	
37. Grey chalk (*craie siliceuse*)	12·55	
38. Very hard grey chalk (*craie siliceuse*)	13·45	
39. Hard chalk, marl	8·30	
40. Very hard grey chalk (*craie siliceuse*)	6·99	
41. Very hard grey chalk, with green grains—glauconite	0·90	Upper Greensand.
42. Compact grey micaceous clay	1·30	Gault.
43. Ditto, ditto, ditto, darker, with iron pyrites	3·65	
44. Sandy clay, with green grain and iron pyrites	1·15	
45. Brown clay, with coarse grains of quartz and iron pyrites	1·70	
46. Sandstone, with green grains, very hard	5·31	Lower Greensand.
47. Ditto, less compact	14·50(?)	
Calcareous and shaly beds (carboniferous)	10·36(?)	*Palæozoic strata.*
Total	346·86	

A spring of water was met with at a depth of 160 mètres; but, as it was brackish and did not rise to the surface, it proved useless.

HAMES-BUCRE, NEAR GUINES.—BORING FOR COAL.

(From Degousse's and Laurent's "Guide du Sondeur," Pl. XLIX.)

	Mètres.	
Vegetable earth	2·0	
White chalk with flints	106·0	Middle chalk.
Bluish chalk marl	4·0	Lower chalk.
Greenish grey chalk	4·0	
Greenish chalk	28·0	
Dark grey chalk	50·0	
Clayey greensand	0·20	Upper Greensand.
Black clay	9·80	Gault.
Red schists (Devonian rocks)	2·0	*Palæozoic strata.*
Total	204·0	

Borings in the Boulonnais.

(Communicated to the Author by M. E. Rigaux, of Boulogne.)

"A boring was made (two years ago) at Le Bail, 1½ mile north-west from Marquise.

"They found there 90 feet Oxford clay inferior,
100 feet Kelloway and Great Oolite,
under these the red *Devonian* dolomite of Beaulieu; they could recognise that this bed and the red and grey shales underneath had a dip of 45°, but they could not determine on what side the dip was.

"We have in our museum (of Boulogne) specimens of some old borings, two of which are near Loquingoie. One at Fouquesolles has gone through 300 feet of violaceous shales and greenish grit and got to Devonian limestone. The second one at Rebergues was in the white sands and sandstone, which overlie the red shales (*Devonian strata*).

"At a boring at Houllefort 3 miles south of Hardinghen they found grey shales which they looked upon as the same as the *Silurian* shales found at the boring at Caffiers."

At the following places the older rocks were reached under overlying cretaceous strata, but no particulars of depth are given:—

"Leubringhem.—Reddish shales } *Devonian strata.*
"Landrethun.—Grey or whitish shales }
"Caffiers, 1837.—Slaty shales—(*Silurian strata*).
"Celles (near Desvres).—Greyish or light blue shales.

OSTEND.—Artesian Well.

(From the "Proceedings of the Société Paléontologique de Belgique about 1863.")

	Mètres.	
1. Vegetable earth	0·25	Alluvial beds.
2. Fine grey sand	1·15	
3. Very sandy greyish yellow clay	0·50	
4. Ditto grey ditto.	0·80	
5. Grey sand mixed with shells, and a little peat	2·40	
6. Peat	1·55	
7. Sandy, bluish grey clay	2·71	
8. Bluish grey quicksand	6·08	
9. Sand, with a considerable number of shells	2·36	
10. Dark grey clay	4·85	
11. Bluish grey quicksand with shells	3·55	
12. Fragments of shells	0·50	
13. Fragments of shells with rolled pebbles	5·00	
14. Rolled pebbles	1·60	
15. Greenish grey sand	0·45	
16. Bluish grey clay, very tenacious	136·50	London clay.

	Mètres.	
17. Argillaceous sand with some pyrites	3·00	Lower Tertiary strata.
18. Greenish grey sand, full of shells, rolled pebbles, and pyrites	5·00	
19. Indurated clay (Argile petrifiée) with shells . .	4·00	
20. Grey sand with shells	3·00	
21. Grey sand with fragments of shells	4·00	
22. Greenish grey clay containing but little sand. .	1·50	
23. Ditto „ „ with shells and fossils. . .	1·25	
24. Dark grey „ with shells	3·75	
25. Lighter coloured clay	4·90	
26. Sandy clay	4·30	
27. Clay with a larger proportion of sand	3·30	
28. Pure white chalk.	64·00	Cretaceous strata.
29. Marly or greenish grey chalk	2·20	
30. Red calcareous marl	15·80	
31. Fawn-coloured „	9·00	
32. White sand	1·40	
33. Dark coloured slaty rock		*Palæozoic strata.*
Total	300·65	

A first spring was met with at a depth of 173 mètres.
And a second spring at „ 185 „

Mr. Henry Willett remarked, through the Secretary, that Sir John Hawkshaw's borings proved the similarity of the strata on both sides of the Channel, and the last discovery of the Sub-Wealden exploration, viz., the existence of the Kimmeridge clay of the same character as that in the cliffs in the Boulonnais district, seemed to assert the ancient continuity of strata. He thought it was also satisfactorily proved that the same horizontal bedding, observable in the cliffs at Fairlight, was continuous as far as Netherfield, distant about 10 miles in a north-westerly direction. As one fact was worth a dozen theories, it was important that the Netherfield boring should be prosecuted until the Palæozoic strata were reached.

He thought the following questions might be put to the Author with advantage:—

1st. Was there any evidence to show what were the natural causes in operation which effected the separation between England and France?

2ndly. While, as was well known, the destruction of the cliffs by marine erosion was slowly but surely widening the Channel, was there any evidence that the same denuding forces, viz., of storm and tidal currents, were deepening the Straits in any portion of the Channel? This must be the case if the current at the bottom was swift, and if the bottom itself was not protected by marine growth, or by deposit of sand.

3rdly. Did any data exist as to the rate at which this increase of depth proceeded? He could not admit that the Lower Chalk and the Chalk Marl were unsuitable for tunnelling; on the contrary, he thought they were more suitable than any other strata likely to be found in the district. The Wealden strata were notoriously unfit for engineering purposes, first, from the frequency and uncertainty of their faulting, and secondly, from their alternating character of clay and sand. The Kimmeridge clay, if it extended in a horizontal bedding across the narrowest portion of the Channel, and if it were of the same dense structure as the lower beds discovered at Netherfield, would perhaps prove more desirable for tunnelling. There was, however, much virtue in *if*, and the fact that at Bexhill, distant from Fairlight about 3 miles to the eastward, the faulting was so serious, as to suggest the possibility of the strata being actually reversed, did not augur well for an unbroken continuity, unless in the direct line of the anticlinal axis.

Mr. Edward Hull observed, through the Secretary, that no one was better qualified than the Author to advise the eminent engineers who had projected the scheme of the Straits Tunnel regarding

the nature and position of the strata liable to be encountered. Mr. Prestwich's proposal was at once bold and original; and if the question of water were the only one to be considered might be said to solve the problem. But as the depth at which a tunnel in the Palæozoic rocks would have to be driven was admittedly great, questions of gradients, increased cost, &c., here came in, and imposed other problems. Without venturing to pronounce an opinion in the present stage of the inquiry, he had an impression that a line taken in the central or lower portion of the Chalk, from the neighbourhood of the South Foreland to Calais, would present the least number of difficulties. The great thickness, persistency, and uniform mineral character of the Chalk formation, together with the facilities it presented for tunnelling, offered strong inducements in its favour; and should water-bearing fissures be encountered, which would doubtless be the case, they could be dealt with by strong iron tubing.

Mr. William Low stated, through the Secretary, that he could corroborate the importance and value of the Paper, from the geological investigations he made in 1867, previous to fixing the direction of a proposed tunnel under the Channel, for uniting the railway systems of England with those of France. The line of the proposed preliminary driftways, preparatory to the construction of a double tunnel, without sinking a shaft in the Channel, and with the object of obtaining ventilation, both during construction and after completion, started from the English shore at the South Foreland, and was continued in a straight line until it reached the French shore, at a point ½ mile north-east of Sangatte. In that line he expected the bottom of the lower bed of Chalk would lay at a uniform depth of about 450 feet under the level of the sea. And, as near as he could judge, it coincided with the line of strike of the Chalk, which dipped in a north-east direction. There was a difficulty in fixing upon this exactly, as uniformity in the dip of the Chalk beds was uncertain, the dip being probably less steep as it approached the outcrop. He found that, on the English coast, whilst the dip of the Chalk was about 520 feet in 8½ miles, on the French coast it was upwards of 1,000 feet in the same distance. It was doubtful whether this great fall on the French side was uniform, or whether a fault intervened between Sangatte and Calais. The true line of strike of the Chalk at the outcrop and at the level of the sea was found in a straight line between Folkestone, in England, and Wissant, in France. It was the difference in the dip of the Chalk beds in both countries that induced him to suggest to drive the tunnel along the centre of the lower bed of Chalk. Mr. Prest-

wich referred to a tunnel proposed by M. Thomé de Gamond to be carried through the Great Oolite and other measures lying under the Chalk, between Cape Gris-nez and East Ware Bay. This was abandoned by M. de Gamond many years ago; and another engineer and himself signed plans on February 7th, 1868, to be submitted to the French Government, upon which the tunnel was laid down as passing in the lower bed of Chalk from the South Foreland to Sangatte. He was still of opinion that the only practicable line for executing a tunnel between England and France was in the lower bed of Chalk. The difficulties to be overcome in constructing a Channel tunnel appeared insurmountable to those who had not investigated the subject. The geologist was satisfied that, on geological grounds alone, it was in one case perfectly practicable, and in one or two others possibly so. It now lay with the civil and mining engineers to determine whether the difficulties of constructing such a work were, or were not, insurmountable.

Mr. John Evans, F.R.S., wished to express the satisfaction he was sure all must feel at the extremely able manner in which the geological questions involved in the matter under consideration had been brought before the Meeting. Mr. Prestwich admitted the impossibility of a tunnel being constructed through the London clay, or through the lower beds, such as the Kimmeridge clay, overlaid as it might be by the Wealden. His preference was for the Palæozoic rocks, but even in regard to these he admitted that there were important elements of uncertainty. The distance beneath the surface and the position of the Palæozoic rocks on the French side of the Channel were known; but with regard to England there was not sufficient information to enable a definite opinion to be formed. Even if the borings on the English side of the Channel, say in the neighbourhood of Dover, were to meet the Palæozoic rocks at some not inaccessible distance, the existence of any comparatively level ridge between that point and Boulogne or Sangatte would be doubtful. In contorted beds, such as these were known to be, there would, in all probability, be considerable unevenness in the surface against which the Secondary deposits were laid. He imagined that the level of the central part of the proposed tunnel should be the highest, so as to allow of drainage to either end; and at such a depth as 1,000 feet below the sea there must of necessity be a considerable addition to the length of the slanting passages leading into the main or central tunnel, which would add enormously to the expense and difficulty of the work. One geological point had (no doubt accidentally) been omitted, viz., the probable

presence of the Upper Greensand between the Gault and the Lower Chalk. It was a permeable stratum, and would materially interfere with the water-tightness of a tunnel coming in contact with it. If, however, the Lower Chalk rested in almost immediate contact with the Gault clay, there would be a considerable thickness of impervious strata, which would conduce materially to the convenience of the engineer who might undertake the work. With regard to the Chalk, in the neighbourhood of Dover, where unfissured, it was more impervious to water, *i.e.*, the angle of friction of the water passing through it was greater, than in many other parts of England. In some parts, as in Hertfordshire, the incline might be represented by 12 feet 6 inches to the mile; but in the neighbourhood of Dover it required a hydrostatic pressure equal to 40 feet to the mile to enable water to pass through the Chalk, as was shown by the inclination of the stream from Buckland to Dover.

Mr. Homersham thought Mr. Prestwich had passed over the Gault clay too lightly. The reason assigned was its insufficient thickness. He had dealt with that formation in many places, and had ascertained that it was not so thin as was generally supposed by geologists. At Caterham, having first sunk a shaft through the Chalk, he found a thickness of 343 feet of Gault clay before reaching the Lower Greensand. He was not aware that near Folkestone or Dover any borings had been made through the Gault clay where the Chalk was immediately superposed. In sinking a well in Gault clay where it cropped out at the surface of the ground, as at the southern side of the chalk hills known as the North Downs, the Lower Greensand would probably be reached after 20 feet; a little further north it would be 60 feet, and further north still 100 feet. It was not until the Chalk itself had been penetrated, and the Gault clay thus reached, that the full thickness of the formation was encountered, owing to its having been thinned off at places where it appeared at the surface as at Wissant. At Arlesey, where the Upper Greensand was pierced before coming to the Gault clay, the thickness of this formation was 204 feet. He did not know of any borings or wells sunk through the Chalk into and through the Gault that would warrant the Author's confidence as to the extreme thinness of the formation between Folkestone and Dover, and between Cape Gris-nez and Calais. If the Gault was of sufficient thickness for a tunnel, he believed there was no formation through which it could be so successfully carried. It did not swell like the London clay. It was homogeneous, easy to work in, and impermeable to water. There was this advantage

in going through it, that the depth below the surface might be chosen. It dipped down from north to south, or from Folkestone to under Dover and the Thames, and as it crossed the Channel it still dipped in nearly the same direction; therefore by going more to the north or the south, and sinking through the Chalk, the Gault clay could be reached at almost any level desired.

Mr. Warrington Smyth said the Author had referred to several cases in the North of England in which a considerable amount of work had been carried on beneath the sea. Being familiar with those works, he desired to state a few additional facts in connection with them. He wished especially to refer to the importance of carrying out works of exploration for the purpose of selecting the most suitable formation through which to pass. He agreed in the selection of certain beds of an argillaceous character in preference to any other kind of material, especially one likely to contain limestone or chalk. The mines at Whitehaven, belonging to Lord Lonsdale, had been worked to a distance, if followed by the regular roads taken by the colliers, of about 4 miles from the nearest shaft, but considerably less in a straight line. But the principal point to be gained from the experience of those submarine collieries was, that although the Coal Measures were exposed at the bottom of the sea, and in some parts lay bare over considerable areas, the workings had been carried on with a remarkable degree of security and freedom from influx of water, in consequence, as he believed, of the argillaceous character of most of the measures above the seams that were worked. The shafts had an average depth of about 120 to 150 fathoms. In consequence of the numerous up-throw faults or dykes passing out to the westward, the average workings were from about 70 fathoms to 120 or 140 fathoms under the bottom of the water. It had been already recognised that where the depth was less than 70 fathoms, it would be probably insecure to remove large portions of coal, and pillars were accordingly left about 20 yards square. These might, elsewhere, be split or divided down the middle, with perfect freedom from accident, and without the slightest influx of water. Further than this, the pillars had been removed from continuous areas, extending over many acres, without any evil effect; no doubt in consequence of the argillaceous materials above the coal tending to fill up a larger space than they originally occupied, so that there was no movement in the bed of the sea above. Parts of some of these areas were beneath the piers of Whitehaven Harbour, and it did not appear that a crack had been seen in them, or a stone observed out of place. This

was a remarkable instance of large excavations being possible under the sea in strata of which a sufficient portion consisted of thoroughly argillaceous material. A little further north a sad example was presented by the colliery at Workington, which, in 1837, in consequence of the pillars having been worked too thin, and at too small a depth below the sea, was inundated, and almost every soul in the workings perished. A sufficient thickness must be left over such excavations—a thickness sufficient to dam out, not only all the springs occurring in the measures, but also the entire body of sea water. In these Palæozoic rocks it was important to be prepared for the contingency of jointy ground, which might accompany some of the dykes or dislocations. In certain instances, where several of these had ramified from one point, or others had met in one point, it had been found desirable to trust no longer to the usually retentive character of the measures, but to fill up closely excavations of that kind with packing, and to excavate no further in the vicinity. The workings to which he alluded had been carried 2 miles along the shore, and to a distance varying from 2 miles to 3 miles from the shore, and there had been no mishap from breakages of the surface or the influx of water. Passing to the coast of Cornwall, one or two instances might be taken as a warning. There were no measures of an argillaceous kind overlying the mineral ground. The mining was carried on in rocks of a more ancient and a harder character, and the mineral veins were unfortunately in a vertical position, striking upwards towards the bed of the sea. In some of these cases, as at Botallack, the workings had been carried on for many years, sometimes to within a small distance from the sea; yet owing, as it would appear, to a considerable amount of water-tight silt occupying the bed of the sea, the water had no tendency to make its entrance where it might be expected, along the line of the back or the outcrop of the vein. And singular to relate, four or five mines along that coast were remarkable for their exceeding dryness, as compared with average mines of the same depth in the same county. There was, however, an instance in the mine of Levant of the danger which might accrue from excavating ground of that sort to within too small a distance of the sea bottom. Some years ago the miners had passed along the 40-fathom level (*i.e.*, 40 fathoms deep from an adit a little above the level of the sea), and penetrated to a distance of 150 fathoms seaward from a shaft close to the cliff. They there met with favourable ground for tin, and commenced workings, which were ultimately carried

to a height of 15 or 20 fathoms. This, coupled with the excessive rise of the level or gallery that had been driven out from the shore, brought the workings to within less than 20 fathoms of the sea bed. At that point an abundant stream of salt water was cut; but the men, seduced by the favourable appearance of the veins, were constantly advancing and taking away more of the ground. In 1866 great uneasiness was felt. In consequence, he examined the workings from end to end to determine what should be done, and he came to the conclusion that it would be unsafe to advance them a single foot further. The men owed their security to the fact that, instead of a mere chalk or limestone, much fissured, the veins consisted chiefly of a strong quartzose material, which was also fissured, and the salt water poured down in streams. The workings below attained a depth of nearly 300 fathoms from the surface, and men were still working in the deeper parts of the mine. From the dense, hard nature of the vein stuff, the water was unable to do more than find its way through: it dissolved nothing, and washed nothing tangible away. Some of the older miners stated that, between thirty and forty years ago, the stream from the level was as abundant as at the present moment. That was a remarkable fact, as showing the small amount of wear and tear produced by a considerable stream of water, although under great pressure, upon a rock of suitable hardness, and not likely to be decomposed or dissolved. Before an attempt was made to construct a tunnel under the Channel, it was important to ascertain all the facts that could be arrived at by preliminary investigations. It was better to trust to argillaceous material, even of comparatively small thickness, than to a greater thickness of material of another character.

Mr. Bazalgette, C.B., said a few years ago he had to sink a well at Crossness, and expected to get a quantity of pure water from the Chalk; but it turned out brackish, and unfit for the purposes required. The boring was continued with the hope of penetrating the Gault clay to the Lower Greensand, in order to obtain a better supply of water. The Gault clay was reached at a depth of about 800 feet before Ordnance datum, and the stratum proved about 150 feet thick; but the boring having been commenced with the intention of continuing it to the Chalk only, the pipes were so reduced in size, that the boring tools were not sufficient to get through to what was believed to be the required depth, 1,000 feet below the surface. The work had since been in abeyance. Two facts had been ascertained—that, at Crossness, at the depth of nearly 1,000 feet, Gault clay existed, and that the Lower Greensand

was not to be found at that depth. It became a question of the greatest interest to determine whether, if there should be a fault in the Lower Greensand at that point the Old Red Sandstone might not be found in its stead, and the existence of Coal under London be thereby solved.

Mr. W. Topley, of the Geological Survey of England, remarked, through the Secretary, that the Paper might be divided into two parts:—1st, that treating of matters connected with the Channel Tunnel, which had been more or less discussed before; 2ndly, that which was entirely new.

With respect to the first division, it might only be necessary to consider the Chalk in any detail; for although, as the Author had shown, the London clay was well adapted for tunnelling, any tunnel to pass wholly through this formation must be of enormous length. Below the London clay there was no formation worth considering for this purpose till the Chalk Marl was reached. It was not disputed that the Chalk Marl afforded a thick and readily accessible stratum through which a tunnel could be driven; and it was known that this, and the Chalk without flints immediately above it, formed the bed of the Straits of Dover. There was no evidence, either positive or presumptive, of any fault or other disturbance of the strata between the English and the French coasts. The only question of real importance, then, was the amount of water likely to be met with. On this point the Author expressed an unfavourable opinion. The Chalk Marl was known to be a practically impervious stratum; but it, like the higher beds of Chalk, was often traversed by fissures, which gave a ready passage to large quantities of water. It should be remembered, however, that this was chiefly the case where the Chalk lay above the sea level, where water was constantly passing through the rock and enlarging such fissures as already existed. Fissures were sometimes met with in deep wells, or in headings driven from wells far below the line of saturation; but such fissures would certainly be rarer and less important than where the Chalk was above the sea or the line of saturation, and consequently where water passed steadily and constantly through the rocks. The Chalk now beneath the Channel had been there for many ages, and, although it might, in past geological periods, have sometimes been above the sea, and even above the line of saturation, yet the fissures would probably have been but slightly worn and enlarged; and consequently there was the less likelihood of meeting with large bodies of water pouring through them. But even if fissures occurred, the modern methods of pumping would be adequate to

overcome any amount of water which they would be likely to yield. He had elsewhere the discussed feasibility of constructing a tunnel through any of the Secondary formations underlying the Chalk;[1] and he had shown that, in passing from the French to the English side of the Channel, a series both of porous and of impervious beds would be traversed, the former possibly fully charged with water. Tunnelling through them would be almost impossible. The Author suggested that perhaps the Weald clay might abut against the Kimmeridge clay in the bed of the Channel, so that it might be possible to drive a tunnel direct from one to the other, both being mainly (although not entirely) impervious formations. Recent discoveries in the Sub-Wealden boring rendered it unlikely that this was the case. Even if it were so, there were no means of ascertaining where the overlap of the beds took place, or where a tunnel should be driven so as to offer the least chance of meeting with the Portland or Hastings sands. Tapping either of these beds would probably be fatal to the undertaking.

The Author broke new ground when he introduced the Palæozoic rocks into the question. No geologist now doubted that beneath the south-east of England and the north-west of France there was a floor of Palæozoic rocks, the depth and range of which were wholly independent of the range of the Secondary and Tertiary rocks above. Where these rocks had been reached, in wells or in borings, or explored by actual workings, they were generally free from water, the exceptions being some cases where Carboniferous Limestone occurred. If a tunnel could be driven through these rocks (other than limestones), it was almost certain that no trouble would be felt from the presence of water. The chief difficulty in the matter was the depth, and consequently the long approaches which must be made at either end, thus enormously lengthening the tunnel and increasing the expense. The maps and sections submitted to the Institution by the Author, embodied all the known facts as to the depth, &c., of these rocks. The only hope of taking a tunnel through them lay in the chance, that they might somewhere be at a less depth near the shores of the Channel than borings had hitherto proved them to be. The Author supposed that the strike of the Palæozoic rocks, which could be observed near Marquise, would continue across the Channel, and that on the English side, along the same line which would come near Folkestone, there would be a ridge of old rocks at no great depth from the surface. The old rocks attained a height of 370 feet above the sea

[1] *Vide* "Quarterly Journal of Science" for April 1872.

near Ferques, but along the presumed line of the ridge they sloped down so rapidly as to be beneath the sea level at Wissant; how far beneath was not known. If this slope continued, their depth beneath the sea at Folkestone would be considerable. Many considerations led to the inference, that the Palæozoic floor in the south-east of England would generally be found at a depth not much exceeding 1,000 feet below the sea; sometimes at a less depth than this. It was probable that it would be somewhat nearer the surface along the strike of the ridge which traversed the north-eastern corner of the Bas Boulonnais; but the exact direction on the English side could only be known by experimental borings. The Sub-Wealden boring could not fail to yield important information upon this point. If further explorations were determined upon, it was desirable that the boring in St. Margaret's Bay should be continued; probably an additional depth of 150 feet there would reach the Palæozoic rocks. It should be borne in mind that such explorations would also throw important light upon the question of the occurrence of the Coal Measures beneath the south-east of England. In connection with the possible depth of the Palæozoic rocks at Folkestone, Mr. Prestwich had referred to the supposed thickness of the Weald clay at Hythe. Mr. Topley stated that near Leith Hill this clay was about 1,000 feet thick; at Maidstone it was 600 feet. If it thinned regularly to the east, it might be expected to be about 350 feet thick at Hythe; and he thought its thickness there would not greatly exceed that amount.

Captain Tyler said he had for many years taken great interest in this question, and had referred to it at some length in an official report in 1869, in which he had enumerated the different schemes that had been brought forward. Since then the project had been in abeyance; but he hailed with pleasure the reading of this Paper, as a new starting-point for the undertaking. The Author had ably and concisely stated all that was known as to the geological conditions of the Channel, upon which must be founded any decision as to further explorations with a view to solve the question under consideration. The Paper consisted partly of a statement of facts and partly of deductions from those facts, and it was the latter which the Meeting had principally to discuss. It was stated that a tunnel through the London clay would require to be 80, or 90, or 100 miles in length, which was quite enough to put that formation out of court. It was considered that it would be inexpedient, or it might be impossible, to work through even the lower part of the Chalk formation in consequence of (1) difficulties connected with

land springs; (2) the probable occurrence of faults or fissures; and (3) the dangers of leakage through the exposed Chalk at the bottom of the Channel. Preference was given to the Palæozoic rocks. No alarm was experienced at the idea of tunnelling through Silurian slates, or Devonian or other limestones; and there was evidently a lingering notion that coal might be extracted during the progress of the tunnel. That was, no doubt, a tempting prospect,—the idea of realising 40*s.* a ton for the excavated materials. But the practical question was, what further explorations should be made? Considering the length of a tunnel through the clay, and the evidently great but uncertain depth of a tunnel through the Palæozoic rocks, the safe and middle course seemed to be a further exploration, as had been proposed, through the Lower or Grey Chalk. Land springs might prove an obstacle; but these would be found at the commencement of the work, and before any serious expense had been incurred. With regard to leakage, any one who knew much of the Lower Chalk would be pretty well convinced that the impermeability of the argillaceous Chalk Marl at a considerable depth was so great as to afford every probability of success, if only drift ways were successfully pushed in the first instance to a distance of $\frac{1}{2}$ a mile from the land on each side. There was, of course, a possibility of meeting with faults or fissures; but there was also a probability that they would be completely choked up by material as impermeable, at the depth of the tunnel, as the Grey Chalk itself. It appeared to him that the prospect of success was sufficient to justify an attempt at boring through the Chalk from each side of the Channel. It was hardly possible, indeed, to test the problem in any other way. The difficulty and expense of boring vertically through the water in the Channel would be considerable; a number of such bore holes would be necessary in order to afford any degree of certain information; and they might, even if they were carried out, cause mischief by creating, so to speak, the very fissures which it was so desirable to avoid. All must admit the necessity for an improvement of the present means of communication across the Channel; and those who were in favour of a tunnel should not consider as rivals any other schemes having that object in view. There were three or four hundred thousand persons crossing every year, in spite of the inadequate facilities afforded for the passage, and in spite of the disturbed weather that prevailed for three quarters of the year. These numbers would soon be doubled if the facilities for crossing were increased; and it was to be hoped some of the

vessels now in course of construction would tend to that result. The greater the number of persons crossing the greater would be the necessity for the future construction of a tunnel. If it should be found that the Gault below the Chalk Marl was a sufficient protection against water from below, that the vast mass of the Chalk Marl was itself a sufficient protection against water from above, and that the land springs were not too great an obstacle to the progress of the work for the first ½ mile from each shore, then hope might be entertained of the ultimate success of the project. A tunnel 20 miles long under the sea, with 5 miles of approaches at either end, would be in any case a gigantic operation; but provided only that the work was not stopped by water, it was not in reality so formidable as might appear at first sight. In the Mont Cenis tunnel, 7¾ miles long, every yard of rock had to be drilled and blown away by gunpowder; and he had seen the steel jumpers, worked by machinery, losing their edges and exchanged for others, whilst apparently making little impression for half an hour at a time upon the opaque quartz rock, which extended through a distance of 300 mètres in that tunnel. The cutting away of the Chalk Marl under the Channel would be comparatively an easy operation. Not only would much less labour be necessary, but the work would progress with far greater rapidity, only to be measured by the arrangements for the removal of the material as fast as it could be cut away from the faces of the headings. And it was easy to conceive that the real difficulties to be encountered might not be in the excavation of the 20 miles under the sea, but in the sinking of the shafts, and in the construction of the land approaches. Some persons feared that a tunnel might facilitate an invasion of the country by foreign powers. There need, however, be no apprehension on that score; for though it might be difficult to get through the tunnel without too much water, it would be easy to contrive means of letting in water if desired. It would also be easy to deposit adequate quantities of gunpowder at given points to be exploded by means of electric wires from any desired positions. If a hostile army were to enter the tunnel, the old drama of a certain host being drowned in the Red Sea might be repeated on a larger scale and with equally satisfactory results.

Professor RAMSAY thought it might be possible to make a tunnel through the London clay, but its length would, in his opinion, be an insuperable barrier. The project of a tunnel through the Palæozoic rocks was so problematical that it could hardly be entertained as feasible. No one knew at what depth the

Palæozoic rocks lay on this side of the Channel. In the Wealden exploration, now going on, they were not expected to be found at a less depth than about 800 feet, and the depth was not likely to be more accessible between that boring and the coast. To go westward, to a point where they cropped up to the surface, would add more than 130 miles to the length of the tunnel, and no man knew at what depth they might lie between that point and the Wealden boring. If it happened that the Kimmeridge and the Wealden clays came together, it might be possible to make a tunnel through them without serious difficulty; but the general feeling seemed to be in favour of the Cretaceous strata. It was said that the Gault was much thicker than was usually supposed. It was known to be much thicker in some other areas than it was in the Wealden area—the district near which it was considered the tunnel could be best constructed. From personal knowledge he could state that it was there so thin that it could not be relied on for the passing of a tunnel through it from one side of the Channel to the other. The dip of the strata all across the Channel was not known with anything like precision, and no one could say that it might not vary considerably. The line of outcrop of the Gault and the Upper Greensand (which was also exceedingly thin), and of the base of the Chalk, would not be straight, but somewhat sinuous, depending on the angle of inclination of the strata, and the denudation they had undergone, either beneath the sea or before they were depressed beneath the sea level. To execute a tunnel, therefore, with anything like certainty, it would be necessary to begin in a set of strata of considerable thickness, and not immediately near the outcrop. The partially argillaceous beds lying at the base of the Chalk were not of great thickness, but were thick enough to render it certain that they might be bored through all the way, making allowance for unknown accidental circumstances; but if the dip varied, the boring would have to follow the sinuous line described by the strata under the level of the sea. No doubt fissures might occur; but there was no reason to suppose that there was any great line of fault passing through the Channel: there was no proof of it, and no absolute proof against it. But considering how little the Chalk was fractured by important faults on the English side of the Channel, and how regularly it lay on the opposite side, he did not think it likely that there would be a disturbance by any serious faults. There were often fissures at the surface, but such fissures were apt to be closed at great depths, and were not likely to be of any importance in passing through one stratum of chalk into another. There was a

difficulty, however, which he thought of some importance, namely, the existence throughout the Chalk districts of pot-holes. Water from the surrounding area ran into these holes, disappeared in the Chalk, and went down to unknown depths. Any one who had examined deep railway cuttings must have been struck with the frequency of these pot-holes, which were filled not only with clay, but often with sand, to a considerable depth. There was no reason why these sinuous veins of sand might not go down to almost an unknown depth in the Chalk. It would have to be considered whether or not they might not pass through the marly Cretaceous strata lying towards the base of the Chalk. There was so much calcareous matter in the greater part of these subformations of chalk, that it might be a question whether much of it might not in the course of time be dissolved by the carbonic acid absorbed by the rain water falling through the Cretaceous strata, and whether these pot-holes might not be produced even towards the base of the Chalk formation itself. He did not suppose that the permeability of the Chalk to water, in a general way, was so extreme that it could not be overcome by ingenuity and mechanical appliances; but the obstacle to which he had referred was one that it might be more difficult to encounter. There was another point to which attention should also be drawn. In passing in a straight, or approximately straight, line through these strata, it would be necessary to take into account the possible sinuosity of the line that would mark the junction of the true Chalk with the Chalk Marl.

Sir John Hawkshaw, Past-President, said there were several points connected with the project (for at present it was only a project), with regard to which geologists appeared to require some information. In the first place the project, so far as he was concerned, was not put forward without consideration. It was long since he first thought of the practicability of a tunnel across the Channel; and in 1864–5, feeling dissatisfied with the geological information then obtainable, he employed Mr. H. Day, a practical geologist, who could also use the spirit level, to investigate the matter. He spent some months in ascertaining the outcrop and depth of the strata on both sides of the Channel; and when he had completed his labours, he made an accurate chart of the region in which it appeared that the tunnel would have to pass. He still felt that was not sufficient, and that a more extensive inquiry would be required. Accordingly his friend, the late Mr. Brassey, Mr. George Wythes, and himself, were at the expense of further investigations, which consisted of borings through the Chalk on the English coast, and

borings of great depth on the French coast. Then arose the question whether the Chalk was continuous. There were suggestions as to the existence of a great fault. It was thought by some persons that the Channel might have been formed by the strata being riven asunder, and that the Chalk might not be continuous. In order to obtain information on the subject they had a steamer in the Channel for several months under the charge of Mr. Henry Brunel, who, with an apparatus contrived for the purpose, examined the bottom of the Channel for a considerable breadth all across and in the line that the tunnel would probably take. These investigations showed, as far as such investigations could show, that the Chalk was continuous; and they afforded remarkable proofs of the accuracy of Mr. Day's observations, for the outcrop at the bottom of the Channel was found very nearly to coincide with that which he had predicted from his geological inquiries. Having ascertained the outcrop of the strata and the dip, his endeavour was to place the tunnel so that it would run, except at the sides, uniformly through the Grey Chalk, and the question now was whether that was the proper place to put it. There was an observation which he had made over and over again, viz.: that at a sufficient depth it was of no more consequence having the sea above the tunnel than having a mountain above it. But then there were other considerations involved in the question. In going down a thousand feet deep it would be necessary to begin a long way off to get to such a depth, and the tunnel would be very long. Unless the tunnel could be so laid out as to pass at a moderate depth under the bed of the Channel, it would be no use proposing it at all. The tunnel proposed by himself and Mr. Brunlees would be about 23 miles in length, and would be nowhere less than 200 feet below the bottom of the Channel. It could be approached from Dover by a gradient of 1 in 80, and it would emerge on the French coast by a similar gradient, so that it could be connected with the railways going to Calais, Boulogne, and Paris. So far, therefore, it was in an engineering point of view in the right situation. With regard to the question of water, he might be permitted to say that land springs, which seemed so serious to the geologists, would not deter an engineer from making a tunnel through chalk. He was now completing, at Brighton, a tunnel $5\frac{1}{4}$ miles in length, wholly through the Upper Chalk, and below the level, and within a short distance of the sea. There was a large amount of water from land springs. The quantity of water pumped in constructing this tunnel varied from 8,600 to 10,000 gallons a minute. This was a large quantity, but it did not prevent the tunnel from proceeding,

and he expected that in three or four months it would be completed. In like manner water in the Chalk would not prevent the construction of a tunnel across the Channel. The only thing that would prevent it would be some direct and open fissure, of considerable magnitude, communicating with the sea, and leading to an irruption of water too large to be dealt with; and the question for geologists to consider was whether it was possible, or likely, that such a fissure could exist, and extend to the depth of 200 feet below the bottom of the sea. His own impression was that no such fissure would be found. It was not unlikely that there might be fissures, but he believed that in the countless ages which applied to geological formations they would have become filled up. A large provision, however, had been made for meeting any contingency of that kind, so much so that some persons thought it too large. In the construction of the tunnel at Brighton, twelve pumps were employed. The engines were, in the aggregate, of 150 horse-power, but provision had been made, in estimating the possible cost of the Channel tunnel, for engines of about 2,000 horse-power. The construction of a tunnel like that at Brighton was absolutely exposed to more annoyance from water than the Channel tunnel would be, because it was shallower, and in order to get the work done rapidly it was opened out at a great variety of places into which the water came at the same time; but that could not well be done with the Channel tunnel. The driftways and the tunnel itself could be lined with brickwork as soon as the excavation was made, so that he did not believe, as regarded the ordinary percolation of water, or water from land springs, there would be more trouble with it than at Brighton. The chief difficulty would be, he believed, on the sea-coast. The Grey Chalk could not be reached on either shore without going through the White Chalk; but the Chalk appeared to him to be, on the whole, the best formation for the tunnel. Of course the work was not to be undertaken lightly. The conclusion he had arrived at long since was, that it was a work of which there was a reasonable prospect of success, the only risk being the possibility of a fissure between the sea bottom and the tunnel; but this could be ascertained, in the first instance, by driving driftways from each side. If the tunnel were made through clay and soft material it would be necessary to timber the whole distance. One of the most troublesome operations would be to get the materials in and out; and if timber as well as bricks should be required, the operation would be greatly delayed. It had occurred to him that this might be done by means of two pneumatic tubes like those used by the Post Office, which

conveyed easily a ton or a ton and a half in a wagon. One tube could bring out the Chalk, and the other take in the bricks; and they would at the same time serve for ventilation. He believed that some day this important work would be carried into execution.

Mr. Rawlinson, C.B., said it did not follow that springs, such as those referred to by Sir John Hawkshaw, passed to any great distance under the sea, or that there was much interchange between the ocean water and the strata below. He had sunk wells in places near the sea, and much below the low-water level, but sea water did not penetrate the strata. At Worthing, in the Chalk, a well and bore-hole had been sunk about 400 feet. There were, however, all round the coasts of Great Britain mines and wells existing near the sea, and under it, to which salt water did not penetrate, the strata having been solidified so as to bear without leaking the vast pressure of the ocean above. Many persons imagined that it was only required to go deep enough into the earth to get water in abundance. Those who had sometimes to seek for it knew the contrary. In the North of England, where mining operations were carried on, floods of water were met with at a depth of 500 or 600 feet, but on reaching a depth of 1,000 feet the water disappeared. He did not believe that below the bed of the sea there could exist any such open fissure, as had been surmised, that would seriously interfere with the operations of tunnelling. On the contrary, he thought the whole stratification, of whatever character it might be, in the enormous period that had elapsed, would have been grouted and compressed by the superincumbent mass of water, so as to be solid, cohesive, and impervious. It had been suggested that there might be pot-holes which had existed in past ages before the submergence of the land. No doubt in railway cuttings such pot-holes were found; but he was not aware that they extended to anything like 200 feet in depth. The pot-holes alluded to had an origin easy of explanation. The water falling upon the surface was rain water, which dissolved chalk. Where there was a depression of a basin-shape the water flowed in, dissolved the Chalk, and if there was an escape below, carried it away, and the gravel from the surface sunk in and filled the cone-shaped space; hence the formation of pot-holes. But how could such formations occur at the bottom of the ocean? If they had ever existed, they must long since have been silted up and have disappeared. He believed that when the Engineers who had to carry out the work had got a short distance from the shores on both

sides, they would no longer be troubled with water, at any rate not in the overwhelming quantities some persons anticipated.

Professor Ramsay said the Chalk had not always been in its present position relatively to the sea. England and France were once joined. The bridge across was a bridge of chalk, and England had been separated from the Continent by denudation. The Chalk was formerly high above the level of the water; and it was under these circumstances that pot-holes at a great depth might have been formed; and the relics of such pot-holes might now exist below the water, though the immediate surface of the Chalk that once united the two countries had been destroyed by denuding agents.

Mr. Bateman, V.P., said every one must sympathise with those who desired to improve the communication between England and the Continent, for nothing could be more wretched than the existing means. It was refreshing to hear Sir John Hawkshaw and Mr. Rawlinson express so confident an opinion as to the possibility of making a tunnel under the bed of the Channel; but he could not help thinking the difficulties that would have to be encountered were much underrated. Mr. Prestwich's Paper was exceedingly appropriate, considering how much the engineering operations depended upon proper geological knowledge; and the members must feel indebted to him for having so clearly stated the probabilities of position and superposition of the strata intervening between this country and the Continent. There was probably no gentleman who, from extensive knowledge and cautious observation, was better qualified to determine, within such bounds as the question permitted, the character of the material to be dealt with. But, after all, what was the whole question but one of speculation? Certain observations had been made on each side of the Channel, and Sir John Hawkshaw stated that experiments were undertaken with a view of ascertaining whether the Chalk found on both sides was continuous. Every geologist, and every one who had tunnelled, knew that a rock might be continuous, and yet highly fractured. Every gentleman who had spoken or written on the subject, had mentioned the possibility and probability of faults existing. The distance was at least 20 miles; and it was impossible to determine beforehand what were the probabilities of faults or dislocations occurring between one side and the other. Almost every valley was merely denuded ground, following the line of the greatest dislocation of several which were parallel. He had had, in many cases, to dig deep trenches across beds of rivers for the

purpose of making reservoir-embankments; and he had rarely, if ever, crossed a valley at any great depth without encountering a dislocation. All the great rivers in the country owed their primary origin to dislocation; and the question had been pertinently asked, What was the original cause of the disruption between England and the Continent? If the denudation which had taken place, and had separated one country from another, had followed a line of fault or dislocation, and if the fault should be a water-bearing fault, no human agency could overcome the difficulty of the irruption of water. Faults varied according to the nature of the rocks which they traversed. Those passing through argillaceous measures no doubt occasionally puddled themselves—made themselves water-tight by the infiltration of the softened material of the rocks; but this was not the case with harder rocks. In arenaceous rocks the faults were generally dry; and the infiltration of argillaceous matter from above did not, he believed, extend to any great depth. Taking the case of a fracture in the Coal Measures, or in the Millstone Grit, with alternating beds of shale and stone one after the other; the fissure below the bed of shale might, for a short distance, be filled with argillaceous matter, but it did not extend to any great distance, nor was it of any great consistency; and far down below the shale would be found an open, cavernous crack, that would pass water in abundance. The source of the water, if a fracture were met with, would be the sea, and no human agency could exhaust the water supplied by so copious a reservoir. He did not desire to throw any doubt upon the tunnel beyond that which was reasonably required before so gigantic an undertaking was attempted; but he would be a bold man to commence a tunnel without considering, at all events, the possibility of the existence of fractures of such a nature as to overcome all efforts to drive a tunnel through them. The Paper was entirely geological, and it ought to be studied and discussed in a geological spirit. Mr. Prestwich discarded the London clay, because, he said, a tunnel through that formation would be 100 miles in length. He also discarded in succession every formation until he reached the Kimmeridge clay. He thought it possible that half-way across the Channel, beginning on the French side, that clay would be deep enough and in sufficient mass to enable a tunnel to be driven through it, and that it might there meet with another impervious formation, the Wealden, and pass into it. If he understood the Paper aright, the Author stated that it would be necessary to follow the dip; but for engineers to follow up and down the sinuosity of a bed of clay, without any

means of ascertaining the thickness, or the position, or the depth, would, he thought, be an impossibility. The Palæozoic rocks, as far as his experience went, were more highly fissured, and more permeable to water than any others. They contained the Coal Measures, the Millstone Grit, the Carboniferous Limestone, and the Old Red Sandstone. Below these were the Primary rocks, which he believed were almost absolutely free from water. All the rocks from the Old Red Sandstone to the New Red Sandstone were arenaceous or limestone; the one breaking with a dry fracture like an old drain, and the other breaking with a fracture that allowed the water to melt and dissolve it, as it were, and enlarge any cavern that might exist. Professor Ramsay, speaking as a geologist, said that there was a time when these pot-holes of gravel or other matters on the surface of the Chalk were deposited, and when the whole bed below the Channel was above the surface of the water; that fissures enlarged then by the penetration of water would still exist; that when they were dropped below the surface they would still be there; and if there were an outcrop of the various measures notoriously permeable to water, such as the Upper and Lower Greensand, or the Hastings sands, and other sand beds occurring in the various measures lying immediately below and above the Chalk—if any such measures were met with, he believed the water would pass freely through them, and that no mechanical means at the command of man would enable engineers to overcome the difficulty. On the whole, he thought that the Paper was not encouraging to the advocates of a Channel tunnel. A tunnel through the London clay would, as he had said, be an impossibility; and most of those who had paid attention to the thicknesses, and position, and circumstances of the various measures which would have to be considered, would probably agree with him in rejecting all the rocks down to the Palæozoic, except the London clay, and possibly the Kimmeridge clay. With regard to the Palæozoic rocks, there was no certainty whatever. These were said to be at a depth of 1,000 or 1,100 feet, and then it would be necessary to go to a greater depth to be clear of water. This depth, with an inclination of 1 in 50, would greatly increase the length of the tunnel; and if the tunnel were 1,000 feet only below the level of the sea, there would be an approach of 10 miles at each end, not including the elevation of the ground above the surface of the water, so that there would be a tunnel between 40 and 50 miles long. With regard to the Gault, he agreed with the Author that it was generally of small dimensions. Mr. Bazalgette and Mr. Homersham had spoken of piercing

330 and 500 feet of Gault, and it was therefore thought that Mr. Prestwich might be wrong in the dimensions stated; but the whole was involved in uncertainty. He inferred, from the Paper, that the opinion of the Author, like that of geologists generally, was against the feasibility of the project. If Sir John Hawkshaw and his adherents could satisfy the public and themselves that the Chalk through which they desired to take the tunnel was continuous, and offered no objections that could not be overcome, he wished them all possible success, and should be delighted to be amongst the first to travel through the tunnel when it was completed. The ardent geologist broke out at the end of the Paper. Like Mr. Godwin Austen, the Author appeared to be impressed with a belief that Coal Measures rose to within a comparatively short distance of the Weald clay in Sussex, and he was engaged in a boring operation to ascertain what rocks were below the Weald clay in that part of the country, "and," added Mr. Prestwich, "the tunnel underneath the Channel would assist in determining that important question." No doubt it would.

Mr. Russell Aitken could not agree with geologists in the lengths to which they pushed the deductions obtained from their science. Some years ago he was engaged in the construction of a tunnel in the Coal Measures, and when the Bill was before Parliament, it was stated by geologists that there was every reason to expect a length of $\frac{3}{4}$ or $\frac{1}{2}$ mile of the tunnel would have to be driven through a peculiarly hard trap rock, and that it would be therefore enormously expensive. In making the tunnel, however, there was only found a wall of about 12 feet of this kind of trap. There was nothing certain in geology as a science but its uncertainty. He thought that if the Channel tunnel were made, it would have to be driven within a reasonable depth from the surface. If it were at a great depth, it would involve long entrance tunnels at both ends, and these tunnels would require to traverse for considerable distances the water-bearing strata underneath the Chalk. When engaged on the Admiralty Pier works at Dover, he had observed, in laying the foundation courses of the piers, that the surface of the Chalk, except near the shore, was to a depth of several feet in a pasty condition, not at all dissimilar to good puddle. Under these circumstances he thought it not unlikely that but little water would be found in a tunnel driven in the Lower Chalk.

Mr. F. W. Shields said about four years ago the promoters of the undertaking applied to Government for a grant in aid, and he was instructed to report upon the subject. First he considered the probability of the sea water permeating through a

fissure, or otherwise, into the Lower Chalk stratum selected for the tunnel. In making inquiries as to what depth wells had been sunk in the immediate vicinity of the coast, he ascertained that one had been sunk to a considerable depth below the sea, to supply Dover Castle, together with galleries or drift-ways from it, in different directions, in order to collect a larger supply of water; and the contractor who executed the work informed him that the water from the well was perfectly sweet, without the slightest taint of salt. If this was so in the fissured beds of the Upper Chalk, it followed of course that the comparatively solid state of the Lower Chalk would be still more likely to be free from the irruption of sea water. It appeared also, from Sir John Hawkshaw's investigations, that chalk existed along the entire surface of the bed of the Channel, except about 3 miles from Calais, which might be accounted for by the great mass of sand drift in the neighbourhood of Calais which was washed over the Chalk. He had no doubt that the bed of the sea had been puddled, by the action of the tides washing the softened chalk backwards and forwards, and had become impermeable. He believed no one experienced in well-sinking would say that he had got water out of the Grey Chalk, for as soon as that formation was reached the fissures ceased, and the water-bearing strata ceased along with them. Under these circumstances he was favourably impressed with the probability of constructing a tunnel in the Grey Chalk from Dover to Calais as compared with any other direction. By going further west, so as to intersect the Palæozoic strata, instead of getting a bed of tolerable continuity, there would be found a vast variety of strata made up of clay, sand, stone, etc., which would involve the greatest uncertainty. With regard to the possible irruption of water, he did not think that difficulty insuperable, even if it occurred. It appeared to him that in making the drift-way recommended by Sir John Hawkshaw, it would be possible to run a small boring, say from 20 to 25 feet, in advance of the main boring, so as to ascertain beforehand whether any such pervious fissure existed. The main boring would be provided, as a matter of precaution, with an iron shield, which in such a case would be pushed forward so as to pass through the porous stratum into the solid one beyond it. He was encouraged in this view by the fact, that Mr. Bateman had proposed a scheme for laying an iron tube, large enough to hold a railway train, along the bed of the Channel from one side to the other, with an arrangement for such a shield at the head. On the whole, his opinion was favourable to the construction of a tunnel such as Sir John Hawkshaw had

proposed, believing that the stratum he had selected offered far greater chances of success than any other. He had examined the question of the comparative cost of working the tunnel by pneumatic pressure and by locomotive power. The difficulty with locomotive power, which he thought was in every way preferable, was that of ventilation. The subject had not been referred to by the promoters in the documents placed before him, but he thought the best way of working the line by locomotives would be by two small tunnels, one for a train in each direction, sending a current of air for the purpose of ventilation in the direction in which each train ran, there being an engine at one end forcing air into the tunnel, and an engine at the other sucking it out. By this means the whole body of the air in the tunnel would be kept constantly in motion, and the deleterious vapour emitted by the locomotive would be discharged at the end before the succeeding train could overtake it. His calculation was that the cost of ventilation alone in that way, for trains going through every hour, would be about £30,000 a year, and for trains every half hour, about £70,000 a year, these amounts being considerably augmented by the rise of prices at the present day. The work would not, he thought, be remunerative enough to induce its construction by private capital; but the national advantages which would accrue to England, France, Belgium, and Germany rendered its construction by the Governments of those countries a matter worthy of consideration.

Sir JOHN HAWKSHAW said he had not purposely avoided the subject of the permanent ventilation, which he thought might be provided by a simple process. The process would require an engine of about 100 HP., and would not, therefore, be very expensive.

Mr. BRUCE understood the cost of the tunnel to be estimated at £10,000,000. Making allowances for contingencies, he would suppose it to be £12,000,000. In order to make it pay 5 per cent., allowing 50 per cent. for working expenses, £1,200,000 a year of gross receipts would be required; so that, assuming the line to be 28 miles long, it would require to earn £824 per mile per week. The Metropolitan, running through the heart of the population of London, with stations every mile, earned about £1,099 per mile per week; the Lancashire and Yorkshire, £147; the Great Western, £65; and the London and North Western, £105: so that the tunnel—having only stations at the two ends —would have to earn, in order to pay 5 per cent. interest on the cost, nearly as much as the Metropolitan, five and a half times as much per mile as the Lancashire and Yorkshire, going

through populous districts with frequent stations, eight times as much as the London and North Western, and thirteen times as much as the Great Western. He had no doubt as to the possibility of making a tunnel, but the idea of its being an undertaking that would pay was, he feared, quite chimerical.

Mr. Prestwich, in reply, said he had but little to add to the opinions expressed in the Paper. With regard to faults in the Chalk, no one could walk along the chalk cliffs without seeing one every few hundred feet. Mr. Morris had counted as many as ten small faults, of different sizes, in three hundred and forty paces of the chalk cliffs near Ramsgate. These, however, were unimportant; and it would only be from larger ones that any danger need be apprehended, and then not always. The water was now fresh in deep wells in the Chalk near the sea, such as at Dover Castle and at Margate; but if instead of the line of water level being so high inland as to force the land springs seaward, it were lowered or interfered with from any cause, the same fissures which now allowed of the escape of those springs below the sea bottom would serve as channels for the influx of sea water. As for any efficient puddling of the present sea bed, none such was apparent on the top of the adjacent Chalk where overlaid by Tertiary strata, which were deposited in the old seas formerly spread over that formation. Mr. Evans had remarked upon the uncertainty of the depth of the Palæozoic rocks, in consequence of their being contorted and disturbed; but these rocks, after their disturbance, had been so planed down as sometimes to present a perfectly even surface. Notwithstanding their disturbance, they were found within 100 feet of the same level under Calais, Ostend, and Harwich. Further, if there were any irregularity of surface, it was always greatest in a line at right angles to the strike, and was much less in the line of the strike. In the Boulonnais, for example, the Palæozoic rock-surface dipped southward much more rapidly than along the line of strike to the eastward. With regard to the Gault, no doubt if it were as thick as it was in Cambridgeshire, it would offer favourable conditions for the execution of the tunnel; but he was not aware that it was anywhere more than 200 feet thick along its southern outcrop at the foot of the North Downs. At Folkestone it was 130 feet thick. He had estimated it to be 40 feet to 50 feet thick on the opposite coast, and Mr. Topley had arrived at the same figures. Mr. Homersham stated that in order to be sure of its thickness, the Gault must not be taken where it outcropped from under the Chalk; he was not, however, aware of any place in Kent where the Gault had traversed under

Chalk; but on the French coast, at a distance of about 6 miles from the outcrop of Gault, and 9 miles from Calais, it was found to be 32 feet thick, while at Calais it was 26 feet thick. As to the possibility of the Kimmeridge clay in the neighbourhood of Boulogne passing under the Weald clay, near Hythe, without the intervention of Portland sand and stone, so that a tunnel might possibly pass from one clay formation to the other, he had been led to make that observation because in the Boulogne area the Portland beds were so frequently denuded. The suggestion had, however, since this Paper was written, been confirmed by the circumstance that in the deep Sub-Wealden boring at Battle, after passing through the Wealden series, the Kimmeridge clay was at once reached. The boring had passed from one deposit to the other without meeting with Portland beds, or their equivalent. With regard to the depth of the Palæozoic rocks, he had estimated that near Battle they would be found not less than 1,000, nor more than 1,700 feet deep. But Battle was out of the line of strike of the rocks of the Boulonnais. Rising in that district considerably above the sea level they dipped southward rapidly, and by the time they reached Boulogne they were about 1,000 feet beneath the surface of the Kimmeridge clay; whereas on the eastward line of strike, it was doubtful if in that distance the level of those rocks was 100 feet less. The question, however, was, presuming the ridge to be prolonged across the Channel in a N.W. direction, at what depth would it probably be found on this other side? It might be at a depth not exceeding 500 or 600 feet. Near Marquise the old rocks disappeared beneath the surface at about 100 feet above the sea level. Of course it was a matter of uncertainty, and could only be determined by experiment. All that was known was that these rocks did not exceed, at Kentish Town, a depth of 1,000 feet below the sea; that they were at nearly the same depth at Harwich, Calais, and Ostend,[1] and that they came to the surface between Calais and Boulogne. Between this point and Mons they passed beneath Tertiary strata and Chalk all the way; and in no case were they more than 1,200 feet below the surface, and were generally at depths of from 400 feet to 600 feet. With regard to the comparative scarcity of water at great depths, this would occur where the beds were divided vertically into isolated compartments by faults, or where they were protected by overlying impermeable strata, but not otherwise.

[1] "Popular Science Review" for July 1872.

December 16, 1873.

T. HAWKSLEY, President,

in the Chair.

The discussion upon the Paper, No. 1,358, "On the Geological Conditions affecting the Construction of a Tunnel between England and France," by Mr. Joseph Prestwich, was continued throughout the Meeting.

ANNUAL GENERAL MEETING.

December 23, 1873.

T. HAWKSLEY, President,

in the Chair.

The list of members nominated as suitable to fill the several offices in the Council was read.

Messrs. H. Bell, C. Frewer, C. E. Hollingsworth, W. Shield, F. Stevenson, Joseph Taylor, and A. Williams, were requested to act as Scrutineers of the Ballot, for the election of the President, Vice-Presidents, and other Members and Associates of Council for the ensuing year; and it was resolved that the Ballot Papers should be sent for examination every quarter of an hour that the Ballot remained open.

The Ballot having been declared open, the Annual Report of the Council, on the proceedings of the Institution during the past year, was read. (*Vide* page 174.)

Resolved,—That the Report of the Council be received and approved, that it be referred to the Council to be arranged for printing, and that it be circulated with the Minutes of Proceedings in the usual manner.

Resolved,—That the thanks of the Institution are due, and are presented to Messrs. J. Wolfe Barry and Alfred Rumball (acting for William Lloyd), for the comprehensive statement of Receipts and Payments they have prepared; and that Messrs. W. Lloyd and J. Thornhill Harrison be requested to act as Auditors for the ensuing year.

Mr. Barry returned thanks.

The Telford Medals, the Telford and Manby Premiums of Books, and the Miller Prizes, which had been awarded, were presented. (*Vide* pages 192, 193.)

Resolved,—That the thanks of the Institution are justly due, and are presented to the Vice-Presidents and other Members of the Council, for their co-operation with the President, their constant attendance at the Meetings, and their zeal on behalf of the Institution.

Mr. Harrison, Vice-President, returned thanks.

Resolved unanimously,—That the cordial thanks of the Meeting be given to Mr. Hawksley, President, for his strenuous efforts in the interests of the Institution, for his extraordinary attention to the duties of his office, and for the urbanity he has at all times displayed in the Chair.

Mr. Hawksley, President, returned thanks.

Resolved,—That the cordial thanks of the Meeting be given to Mr. Charles Manby, the Honorary Secretary, and to Mr. James Forrest, the Secretary, for their unremitting and zealous services on behalf of the Institution and of the profession.

Mr. Forrest, in the absence of Mr. Manby, returned thanks.

Resolved,—That the best thanks of the Institution be given to Mrs. Hawksley for her great kindness in taking so prominent a part in entertaining the guests on the occasion of the two conversazioni given by Mr. Hawksley during his presidency.

The Ballot having been open more than an hour, the Scrutineers, after examining the papers, announced that the following gentlemen were duly elected :—

President.

THOMAS ELLIOT HARRISON.

Vice-Presidents.

William Henry Barlow, F.R.S.	George Willoughby Hemans.
John Frederic Bateman, F.R.S.	George Robert Stephenson.

OTHER MEMBERS OF COUNCIL.

Members.

James Abernethy.	James Brunlees.
Sir W. G. Armstrong, C.B., F.R.S.	Sir John Coode.
Joseph William Bazalgette, C.B.	William Pole, F.R.S.
George Berkley.	Charles William Siemens, F.R.S.
Frederick Jos. Bramwell, F.R.S.	Sir Jos. Whitworth, Bart., F.R.S.
George Barclay Bruce.	Edward Woods.

Associates.

Major Frank Bolton.

James Staats Forbes. William Newmarch, F.R.S.

Resolved,—That the thanks of the Meeting be given to Messrs. Frewer, Hollingsworth, Bell, Shield, Stevenson, Taylor, and Williams, the Scrutineers, for the promptitude and efficiency with which they have performed the duties of their office; and that the Ballot Papers be destroyed.

ANNUAL REPORT.

Session 1873–74.

The Rules require that, in meeting the members on this occasion, the Council should place on record a statement of the actual position of the Institution. This duty will be performed with great satisfaction, as in every department of the Society's operations there has been a marked and an undoubted advance.

Voting for the Election of Council.

Before dealing with the ordinary business, it will be right to advert to a matter discussed at the last Annual Meeting, in reference to the mode of voting for the election of the Council, when the President promised that this subject should have full consideration. Having carefully examined those clauses of the Charter bearing on the question, the Council unanimously arrived at the conclusion, that the words of the Charter are clear and distinct, and that it is imperative on the General Meeting to make an election solely by the members present thereat. The Council are further of opinion that it is inexpedient to attempt to disturb the existing Charter, which is extremely valuable as it stands, and is in many respects most excellent.

The London International Exhibition of 1874.

During the Session a communication was received from Her Majesty's Commissioners for the Exhibition of 1851, requesting the Council to nominate members of their body to act on a general Committee of advice in connection with the "Civil Engineering, Architectural, and Building Contrivances and Tests" class of the manufacturing division of the London International Exhibition of 1874. In reply to this invitation the Council nominated Mr. Harrison, V.P., Mr. Bateman, V.P., and Sir John Coode, to represent Civil Engineering; Mr. Bramwell, Sir Joseph Whitworth, Bart., and Mr. Woods, to represent Mechanical Engineering; and Sir W. G. Armstrong, C.B., Mr. Stephenson, V.P., and Mr. Siemens, to represent Manufacturing Engineering; with, in addition, Mr. Manby, the Honorary Secretary.

It is most desirable, in the interests of the profession, that every aid and assistance should be rendered to Her Majesty's Commissioners; and the Council trust all the members will endeavour to make the collection of models and of other objects relating to Public Works as full and as complete as possible.

The Roll of the Institution.

The changes in the roll of the Institution during the twelve months ended the 30th of November last have included the election into the Corporation of 17 Members and 137 Associates, the transfer of 13 Associates to the class of Members, and the loss of 1 Honorary Member, 16 Members, and 26 Associates, viz. —by death, 1 Honorary Member, 10 Members, and 17 Associates, —by resignation, 2 Members, and 4 Associates,—and by erasure (owing to the non-payment of subscriptions), 4 Members and 5 Associates. There has thus been a net effective addition of 111. At the date of the previous Report there were on the books 1,883 members of all classes, now that number is 1,994, representing an increase at the rate of nearly 6 per cent. per annum.[1] The Institu-

[1] The tabular statement for the years 1871–72 and 1872–73, of the transfers, elections, deceases, and resignations of the members of all classes belonging to the Corporation, that is, exclusive of the Students (taking into consideration the names which have been erased from the Register), is as follows:—

Year.	Honorary Members.	Members.	Associates.	
1871–72.				
Transferred to Members	..	..	17	
Elections	3	22	115	142 − 45 = 97
Restored to Register	..	..	2	
Deaths	1	9	19	
Resignations	..	1	9	45
Erased from Register	..	1	5	
Members of all Classes on the Books, 30th November, 1872	16	752	1,115	1,883
1872–73.				
Transferred to Members	..	..	13	
Elections	..	17	137	154 − 43 = 111
Deaths	1	10	17	
Resignations	..	2	4	43
Erased from Register	..	4	5	
Members of all Classes on the Books, 30th November, 1873	15	766	1,213	1,994

tion was founded on the 2nd of January, 1818, and has therefore been established nearly fifty-six years. Dividing this into eight equal periods of seven years, the gross number of all grades at the end of each term was 103,[1] 254,[1] 477, 582, 745, 894, 1,339, and 1,994. This shows that 1,100 have been added within fourteen years.

During the last septennial period a class of Students (attached to the Institution) has been created. In the past session, 72 candidates were admitted by the Council as Students, and 53 have been withdrawn from the list, viz.:—3 deaths, 23 resignations, 3 erasures, and 24 elected into the Corporation as Associates. The increase has thus been 19, being at the rate of about $8\frac{1}{4}$ per cent., and making the present total 259. Up to the end of the session 1872–73, when the class had been in existence six years, there had been 398 admissions. Of that number, 304 had been recommended by 127 Members, and 94 by 52 Associates.

Several valued friends and esteemed colleagues—some of them familiar faces at the meetings of the Institution—have been taken away by death during the past year, as will be seen by the following list, viz.:—

Members: Richard Beamish, Joseph Cubitt, William John Forrest, John Robinson M'Clean, *M.P.*, Charles Nixon, Daniel Baddeley Pritchard, James Raine Rushton, Alexander Samuelson, Joel Spiller, and Alfred Harris Vaux.

Associates: Frederick Ayrton, Charles Louis Aimé de Bergue, John Gladstone Davenport, John Evans, Charles Larkin Francis, Thomas Greenwood, Thomas Crump Hambling, Hamilton Edward Harwood, James Archibald Hamilton Holmes, George William Horn, John Jay, William Lang, John Lawson, James Garth Marshall, Frederick Molesworth Pfeil, Thomas Piper, and Alderman Sir David Salomons, *M.P.*

Honorary Member: The Emperor Napoleon.

The resignations of the following Members and Associates have been tendered and accepted:—

Members: Thomas Hardy Bertram and John Joseph Macdonnell.

Associates: *Admiral* Sir Edward Belcher, *K.C.B.*, *Lieut.* Joseph James Curling, *R.E.*, Charles Gilpin, *M.P.*, and William Henry Woods.

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[1] The figures for the seven years ending 1824 and 1831 respectively give the number of elections, no record having been kept of the actual strength at those periods.

Finance.

For some years the receipts have been considerably in excess of the payments. This will be at once apparent when it is remembered, that the first investment on the general account was made in 1860, that a sum of £19,973. 14*s*. 6*d*. has since been paid in respect of the New Building and its appointments, and that to meet this outlay the sole resources beyond the current receipts were the unconditional bequests of Stephenson, Locke, Errington, Miller, and Appold, together amounting to £9,000. The balance of £10,973. 14*s*. 6*d*. has been entirely provided out of the Funds of the Institution, and the nominal or par value of the investments is at present £16,244. 1*s*. 8*d*., representing savings at the rate of something like £2,000 per annum for the last fourteen years. In round numbers, it may be said, that the receipts are now nearly £9,000 per annum, while the ordinary expenditure is about £6,000 per annum. One moiety of the excess arises mainly from entrance-fees and life compositions—sums which, according to the present Bye-Laws, should be, as heretofore, invested on capital account. But, the finances being in a sound and healthy condition, there is no reason why the other moiety, £1,500 a-year, which is fairly assignable to income, should be allowed to accumulate. The Council have therefore under consideration how that sum can be most judiciously and advantageously expended, in promoting the objects and interests of the Corporation and of its members. It appears that there has been no increase in the establishment since the appointment of a Librarian and Assistant to the Secretary at Midsummer, 1864, notwithstanding the rapid growth of the Institution in the interval, from 1,040 to 2,253 (inclusive of the Students) members of the different classes, by which all the regular business has been much increased. In the same period, too, the Proceedings have been enlarged from one volume of 540 pages to two volumes together of 944 pages, the Student class has been created, and the Benevolent Fund has been established, all tending greatly to multiply the duties of the officers.

It has accordingly been decided to make an immediate addition to the staff. The changes and alterations thus proposed will probably absorb from £300 to £400 a-year over and above the present salaries and wages. It has been evident for some time that such an addition would become necessary. This step has only been delayed from a desire not to increase the establishment, so long as the increase could be postponed. In subsequent passages of this Report other proposals will be dealt with, for still further augmenting the usefulness of the Institution.

The Trust Funds.

These Funds are four in number, and arise from—

1. The Bequest of Thomas Telford;
2. The Donation of Charles Manby;
3. The Bequest of Joseph Miller; and
4. The Bequest of Thomas Howard.

1. The Telford Fund proper consists at present of £2,839. 10*s.* 6*d.* Consols and £2,570. 5*s.* 1*d.* Annuities, together £5,409. 15*s.* 7*d.*, and this amount produced £159. 19*s.* 1*d.* in the financial year ended on the 30th of November, 1873. The Bequest was given "in trust, the interest to be expended in Annual Premiums, under the direction of the Council." The expenditure on this account during the last twelve months has been £195. 12*s.* 9*d.* But in many previous years the dividends were not nearly absorbed, and the balances of unexpended income have from time to time been temporarily placed in Government Stocks, to the extent, in the gross, of £2,377. 10*s.* 6*d.* Consols and £637. 6*s.* 10*d.* Annuities, together £3,014. 17*s.* 4*d.*, and the interest on this sum realized in the current year £86. 15*s.* 8*d.* It, therefore, appears that the Fund is still accumulating. It is obviously undesirable that this state of things should continue; and, moreover, the bequest having been accepted, and the trust undertaken, it is clearly incumbent on the Institution to endeavour to carry out the directions of the testator. According to the opinion of Sir Roundell Palmer, the present Lord Chancellor, the Council have full and absolute control over the unexpended dividends, which have been allowed to accumulate, and have been temporarily invested. The Council are seriously entertaining the question, how the original bequest, as well as the accumulations, can be best applied in leading to the production of a superior class of Papers; as, for example, by devoting the accumulations for a series of years, to the offer, under special conditions, of premiums of increased value.

2. The Manby Donation is represented by £200 Great Eastern Railway Norfolk 5 per cent. Preference Stock. It was given "to form a Fund for an Annual Premium or Premiums for Papers read at the meetings." The interest in the year just concluded was £9. 16*s.* 10*d.* One premium has been regularly awarded every session out of this Fund, and the income has been duly expended.

3. The Miller Fund consists of £2,000 Lancashire and Yorkshire Railway 4 per cent. Debenture Stock, and of £1,100 Great Eastern Railway 4 per cent. Debenture Stock, the equivalent of a sum of £3,000, bequeathed by the testator as follows: "for the purpose

of forming a Fund (which I desire may be called the 'Miller Fund') for providing premiums or prizes for the Students of the said Institution, upon the principle of the 'Telford Fund.' And I desire that the said sum of £3,000 be invested, and the dividends and interest thereof applied accordingly." The Fund realized £122. 4*s*. 10*d*. this year, while the expenditure has only been £36. 7*s*. The income on this Fund has never been nearly expended, and as for several years after the receipt of the bequest there were no Students of the Institution, the whole of the dividends were allowed to accumulate. Such accumulations have been placed in £582. 18*s*. 6*d*. Consols, and £856. 15*s*. Annuities—together, £1,439. 13*s*. 6*d*.—and this sum yielded £40. 1*s*. 3*d*. in the current year. Here, again, the Council desire to take immediate action to carry out the expressed conditions of the Trust; and it is only fair to assume that this income might be very profitably used, in stimulating exertion to a greater extent than hitherto among the Students of the Institution.

4. The Howard Bequest of £500, free of legacy duty, was received at the end of 1872, and has since been invested in £551. 14*s*. 6*d*. New Three per Cents. The interest on this sum was directed by the testator "to be applied in such manner and under such conditions and restrictions as the Council of the said Institution may think most expedient, for the purpose of presenting periodically a prize or medal to the author of a treatise on any of the uses or properties of iron, or to the inventor of some new and valuable process relating thereto, such author or inventor being a Member, Graduate, or Associate of the said Institution." The interest this year has amounted to £16. 6*s*. 2*d*.

The Funds.

As a summary to this section of the Report it may be stated, that the Funds now belonging to, or under the charge of, the Corporation—the details of which Funds, both as regards the amounts and the descriptions of the particular stocks held, will be found in the Auditors' Abstract of Receipts and Payments—are as follows:—

	£.	*s*.	*d*.
Institution Investments	16,244	1	8
Trust Funds	13,716	0	11
Total nominal or par value . . .	29,960	2	7
Cash in hands of the Treasurer . . . £279 10 6			
Less petty cash due to the Secretary . 16 4 7			
	263	5	11
Together amounting to . . .	£30,223	8	6

as compared with £28,654. 9*s.* 11*d.* at the date of the last Report. The maximum previously reached was £29,835. 18*s.* on the 30th of November, 1867, before any expenses had been incurred in connection with the New Building—on which account, it may be remarked, a sum of £1,482. 1*s.* 4*d.* has been paid during the last financial year. Of the above Funds, a gross sum of £11,760. 2*s.* 7*d.* is in Government Stocks, and the balance, £18,200, is chiefly in 4 per cent. Debenture Stocks of seven of the leading railway companies.[1]

The Library.

The basis of this collection was the bequest of the Library of the first President, Thomas Telford. The additions since made have been obtained either by presentation, by exchange, or by purchase. In 1851 a Catalogue was issued, and at that date the Institution possessed 3,000 volumes and 1,500 tracts. In this Catalogue one alphabetical arrangement was followed throughout,—a complete transcript of each title-page being given under the Author's name, and the subject entry, in brief, referring simply to the Author. Having been found to answer, the same plan was pursued in the second edition of the Catalogue, published in

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[1] The following is a summary of the different securities in which these Funds are placed:—

	£.	*s.*	*d.*	£.	*s.*	*d.*
Government Stocks:—						
Three per Cent. Consols	5,799	19	6			
Three per Cent. Annuities	3,737	19	2			
New Three per Cents.	2,222	3	11			
				11,760	2	7
Great Eastern Railway:—						
Five per Cent. Preference Stock	200	0	0			
Four per Cent. Debenture Stock	4,750	0	0			
				4,950	0	0
Lancashire and Yorkshire Railway:—						
Four per Cent. Debenture Stock				2,000	0	0
London and North Western Railway:—						
Four per Cent. Debenture Stock				2,500	0	0
London, Brighton, and South Coast Railway:—						
Four per Cent. Debenture Stock	1,000	0	0			
Four and a-Half per Cent. Debenture Stock	1,500	0	0			
				2,500	0	0
North Eastern Railway:—						
Four per Cent. Debenture Stock				3,000	0	0
Great Northern Railway:—						
Four per Cent. Debenture Stock				2,250	0	0
Manchester, Sheffield, and Lincolnshire Railway:—						
Four and a Half per Cent. Debenture Stock				1,000	0	0
Total nominal or par value				£29,960	2	7

1866, when the number of volumes had increased to 5,500, and the tracts to 3,200. A supplement became necessary three years later, and a copy was forwarded to every member, as in the previous instances; and in each following year—that is to say, in 1871, 1872, and 1873—similar continuations have appeared, or will appear, as Appendices to the Annual Reports of the Council, and as part of the "Minutes of Proceedings." As the result of actual enumeration, it has been ascertained that the Library contains 10,443 volumes, including 320 volumes of tracts. In 1851 the Catalogue extended to 228 pages, in 1866 to 412 pages, and the supplements already in type would bring up the quantity to 720 pages—figures which in themselves give an idea of the growth of the collection. It is believed that an entirely new edition of the Catalogue may be required in 1875. It will then be a matter for consideration, whether the one alphabetical dictionary form, both for authors and subjects, shall be preserved—even though more than one volume may be necessary, for the sake of convenience,—or whether any other form should be adopted. After the issue of the next edition of the Catalogue, it is intended that the publication of the list of annual accessions in the "Minutes of Proceedings" shall cease—such list for the future being printed and circulated in a separate pamphlet form.

It is to be regretted that this valuable and unique collection is, like other technical libraries, almost exclusively used for reference, and not for the purposes of study. It will be remembered that when, for a period of upwards of three and a half years, the library was open every day in the week until 10 p.m., so little use was made of the privilege that the evening attendance was discontinued.

The officers of the Institution are constantly in correspondence with Members and others, whether resident at home, or on the Continent of Europe, in the United States, in India and in the British Colonies, with a view to bring into the Library copies of all new books and reports of professional interest as they are printed. Many foreign engineering and scientific periodicals and serials are likewise regularly received, besides the Transactions of Societies. Steps are also taken, on the dispersion of any library, and by continually searching in second-hand booksellers' lists, to obtain copies of all old books and treatises, likely to be of use to the Members, and not already in the Institution. The Council can confidently state, that the Library is in all respects well maintained; and they may add that there is book-shelf accommodation for, in all probability, several years to come

and sufficient wall-space still available for many additional book-cases.

A welcome addition has been made to the series of portraits of former Presidents by the gift of an excellent likeness, by Sir William Boxall, R.A., of the late Mr. James Simpson, who occupied the chair in 1855 and 1856. For this donation the thanks of the members are due to Mr. Simpson's eldest son, who thus offers an example that may well be followed, as the series is still imperfect.

The Ordinary Meetings.

There were twenty-four Ordinary Meetings last session, when only nine Original Communications were read and discussed, being a much less number than usual. This was owing to the extra-ordinary interest manifested in the question—a very important one—of the Gauge for the State Railways in India, the discussion upon which subject occupied seven evenings, and thus necessarily caused the postponement of some Papers which might otherwise have been brought forward. The average attendance at these Meetings, which in 1870–71 was 169, increased in 1871–72 to 181, rose last session to 232. This is still less, by 10, than in the year immediately preceding the reconstruction of the premises. The largest number present on any one evening during the session 1872–73 was 421; previously the maximum was 347, on the occasion of the inauguration of the New Building.

A brief enumeration of the memoirs submitted at these Meetings will show that several different branches of engineering practice were dealt with. These related to:—the Manufacture of Sugar—including a description of the various processes and of some novel machinery lately introduced in Upper Egypt, as well as an investigation of the chemistry and physics connected with that industry; the physical features of Northern India, showing to what extent irrigation has been carried, with notices of the works executed and projected, to avert the terrible famines that periodically recur among the peoples of that portion of the Empire; a method of constructing the foundations of a quay wall in the Clyde at Glasgow, by means of cylinders of concrete, brickwork, and stone-work; the relative advantages of the 5 feet 6 inches (the Standard) Gauge, and of the Metre Gauge for the State Railways of India; the mode adopted in completing the Mont Cenis Tunnel, with a description of the works and machinery, being a sequel to a former communication; the efforts that have been made to introduce Steam Locomotion on Common Roads, embracing also particulars of the most approved types of Traction Engines—for

use on tramways, as steam road rollers, for agricultural operations, steam ploughing, &c.; a railway of a peculiar character in Switzerland, for conveying passengers to the top of the Rigi, involving special arrangements for the rolling-stock; the engineering works carried out on the River Clyde from the earliest times, for the purpose of improving the navigation, as well as of the plans and cost of dredging, removing, and depositing followed in the deepening and the widening of that river; and to the recent changes along the sea coast of the Delta of the Danube, and the consolidation of the provisional works at the Sulina Mouth, being likewise a sequel to a previous Paper.

For these communications the Council have had the satisfaction to award Telford Medals and Premiums to James Deas, William Thomas Thornton, C.B., and Colonel William Wilberforce Harris Greathed, C.B., R.E.; Watt Medals and Telford Premiums to Sir Charles Augustus Hartley,[1] John Head, and William Anderson; Telford Premiums to John Milroy and William Pole,[1] F.R.S.; and the Manby Premium to Thomas Sopwith,[1] junr. A list of the Premiums awarded is given at page 192.

The Supplemental Meetings.

Opportunities were afforded to the Students every fortnight in the months of February, March, and April, and once a week in May, to meet for the purpose of reading and discussing Papers among themselves. These Supplemental Meetings were ten in number. Unfortunately the attendances were less than in the five preceding years; and if the attendances go on diminishing in the same ratio, it is feared that the Meetings will have to be discontinued. Altogether, twelve Papers were submitted, some of which were well and carefully written, showing that much thought and trouble had been bestowed upon them, and reflecting great credit on the Authors. The Council have had pleasure in awarding Miller prizes to Messrs. Frank Salter, B. Sc., John Newman, Alfred Fyson, Joseph Prime Maxwell, Killingworth William Hedges, N. St. Bernard Beardmore, Osbert Henry Howarth, and Charles Graham Smith, in respect of these communications. The discussions were in many cases intelligent, and a readiness was evinced to suggest improved and simpler methods of calculation in abstruse and abstract subjects. These Meetings cannot fail to have a good effect, in facilitating the acquisition of the art of writing and speaking correctly on professional topics, and in cultivating the

[1] Sir Charles Hartley, Mr. Pole, and Mr. T. Sopwith, junr., have previously received Telford Medals.

habit of detecting fallacies both in argument and deduction. With such limited attendances, however, it will always be difficult to secure a satisfactory discussion. Possibly it will be better if there are a less number of Meetings, and if a greater number of Papers are taken at each Meeting. On this point the Students will be consulted, and at the same time they will be informed that the Papers will hereafter be accessible for private study beforehand. These suggestions may probably necessitate condensation, both in the Papers and in the discussions, and greater pains will, therefore, be indispensable. While it is felt that the Students should be encouraged to express their views freely upon the matters under discussion, it is equally felt that they should be discouraged from speaking without due preparation, or on subjects with which they are insufficiently acquainted.

The Conversazione.

The brilliant Meeting with which the session terminated would be passed over in silence, if the well-known wishes and views of the President were consulted; but to this his colleagues cannot consent. Again, as in the previous year, Mr. and Mrs. Hawksley held the Conversazione of the President in the western galleries of the International Exhibition, kindly placed at their disposal by Her Majesty's Commissioners. These galleries contained a collection of British and foreign works of art, both in oil and in water colours, Machinery in Motion relating to the manufacture of silk and velvet, and Mechanical Appliances connected with cookery. Many of the more important articles were also transferred from the Scientific Inventions Court, and a few models, interesting though not numerous, were specially contributed. The exhibitors of the machines and mechanical processes were entirely imbued with the spirit of the entertainment, demonstrating and explaining the details of their work; and their efforts were effectively supplemented by various Members of the Institution. The arrangements were all that could be desired, the evening was passed most agreeably, the gathering was successful in the highest degree, and there is no one who does not gratefully and cordially recognise the hearty, genial, and liberal spirit of the President in this innovation.

The Publications.

The attention of the Council has been devoted to a question of the gravest importance, viz.: How the character, scope, and style of the Original Communications (Papers) read at the Meetings, and the

consequent discussions, can be improved? On this depends, after all, the value of the Proceedings—as indeed the Papers and the reports of the discussions constitute, at present, the "Minutes." It is felt that these "Minutes," recording the Proceedings at the Meetings, are not what they might be, and not what they ought to be. No doubt there have been, and will continue to be, good and sufficient reasons for declining to receive descriptions of untried inventions and of mere projects; but it is believed that memoirs dealing with the engineering and scientific problems involved in a *bonâ fide* work of magnitude about to be constructed—say, for example, the bridge intended to be built over the Frith of Forth—when submitted with the sanction of the Engineer responsible for the work, should be more encouraged in the future than they have been in the past.

Having regard to the number of essays now presented, and to the impossibility, for want of time, of reading and discussing thoroughly more than ten or fifteen communications in each session, it is proposed, as far as possible, to accept for reading at the Meetings only Papers containing principles suitable for discussion, reserving such others as may be accepted, for publication in an Appendix to the Proceedings, either *in extenso* or in abstract. This would introduce what might be regarded as another class of original matter into the volumes—matter, too, which, in one form or other, the Members have for years been invited to contribute, but to which invitation hitherto there has been no response.

The practice, which has been for some time a growing one, of issuing a limited number of proof copies of every Paper, previous to its being read, to any Member or visitor likely to be able and willing to take part in the discussions, will be maintained. And, further, it is intended to place in the Library and Reading Room a dozen proof copies of each Paper, so as to be accessible to all the Members for private consultation there, but not to be taken away, or to be made use of for the purpose of publication.

So far the measures proposed for adding to the value of the Transactions of the Institution pure and simple have alone been referred to—for increasing, in fact, the usefulness of those records of practice and experience, which should embody Original Communications of acknowledged merit, treating of matters of novelty and of special interest to all Engineers. But the Council deem that these alterations are insufficient to meet the exigencies of the case. It has, therefore, been determined to introduce a system which has been found to act beneficially in other societies, both at home and abroad, although it will involve a great change in the

established usage of The Institution of Civil Engineers. This is the organization of a scheme by which the publications of the Institution shall contain a summary of information, gathered from the transactions of foreign engineering societies and from foreign scientific periodicals, on all branches of professional knowledge, so as to afford, in fact, a perfect record, however brief, from year to year, of the progress of engineering science. By this proposal, if systematically carried out, a most valuable and useful addition will be made to the publications; and incidentally it may be expected to lead to a more frequent and a more profitable use of the Library. As it is, many important inventions and discoveries, and many large public works, are entirely unnoticed, because no one is prepared to offer a Paper on the subject. The "Minutes of Proceedings" cannot therefore be regarded as complete works of reference, which, in the interests of the Institution, it is desirable they should be. The Council are of opinion that the surplus funds of the Institution may be thus most advantageously employed, in furtherance of the objects for the advancement of which the Institution was incorporated.

The carrying out of the suggestions contained in this Report will necessitate a larger scientific and general staff, and an increased annual expenditure, which, however, are quite justified by the present excess of receipts over payments.

RECEIPTS AND EXPENDITURE.

ABSTRACT *of* RECEIPTS *and* EXPENDITURE

RECEIPTS.

Dr.	£.	*s.*	*d.*	£.	*s.*	*d.*
To Balance in the hands of the Treasurer				281	11	7
— Subscriptions and Fees:—						
Arrears	177	9	0			
Current	5,908	6	6			
Subscriptions for 1874	61	19	0			
„ 1875 (in part)	2	2	6			
Fees	485	2	0			
Life Compositions	105	0	0			
				6,739	19	0
— Building Fund				738	3	0
— Publication Fund				108	2	0
— Publications :—Sale of Transactions				94	11	5
— Telford Fund :—						
Dividends, 1 Year, on £2,839. 10*s.* 6*d.*, Three per Cent. Consols	83	18	6			
Ditto, 1 Year, on £2,570. 5*s.* 1*d.*, Three per Cent. Reduced	76	0	7			
Ditto, 1 Year, on £2,377. 10*s.* 6*d.*, Three per Cent. Consols (Unexpended Dividends)	70	6	0			
Ditto, 6 Months, on £476. 8*s.* 5*d.*, Three per Cent. Reduced (Unexpended Dividends)	7	0	3			
Ditto, 6 Months on £637. 6*s.* 10*d.*, Ditto, ditto.	9	9	5			
				246	14	9
— Manby Donation :—						
Dividends, 1 Year, on £200, Great Eastern Railway Co. Norfolk, Five per Cent. Preference Stock				9	16	10
— Miller Fund :—						
Dividends, 1 Year, on £2,000, Lancashire and Yorkshire Railway Four per Cent. Debenture Stock	78	15	0			
Ditto, 1 Year, on £1,100, Great Eastern Ditto	43	9	10			
Ditto, 1 Year, on £582. 18*s.* 6*d.*, Three per Cent. Consols (Unexpended Dividends)	17	4	9			
Ditto, 6 Months, on £691. 5*s.* 8*d.*, Three per Cent. Reduced (Unexpended Dividends)	10	3	9			
Ditto, 6 Months. on £856. 15*s.* 0*d.*, Ditto, ditto.	12	12	9			
				162	6	1
—Howard Bequest :—						
Dividends, 1 Year, on £551. 14*s.* 6*d.*, New Three per Cents.				16	6	2
— Institution Investments :—						
Dividends, 1 Year, on £3,650, Great Eastern Railway Four per Cent. Debenture Stock.	143	10	8			
Ditto, 1 Year, on £2,500, London and North Western Ditto	98	8	9			
Ditto, 1 Year, on £1,000, London, Brighton, and South Coast Ditto	39	7	6			
Ditto, 1 Year. on £3,000, North Eastern Ditto	118	2	6			
Ditto, 6 Months, on £1,000, Great Northern Ditto	19	13	4			
Ditto, 6 Months, on £2,250, Ditto, ditto.	44	6	10			
Carried forward	463	9	7	£8,397	10	10

from the 1ST DEC., 1872, *to the* 30TH NOV., 1873.

PAYMENTS.

Cr.	£.	s.	d.	£.	s.	d.
By Balance due to the Secretary				10	16	6
— House, Great George Street, for Rent, &c.:—						
Repairs	445	6	3			
Rent	647	11	11			
Rates and Taxes	69	7	1			
Insurance	20	11	6			
				1,182	16	9
— Salaries				1,150	0	0
— Clerks, Messengers, and Housekeeper				403	12	0
— Donation to late Messenger and Housekeeper				40	0	0
— Postage and Parcels:—						
Postage	82	12	8			
Parcels	0	4	8			
				82	17	4
— Stationery, Engraving, Printing Cards, Circulars, &c.				187	10	0
— Light and Fuel:—						
Coals	35	17	0			
Candles	0	4	0			
Oil	1	10	3			
Gas	51	11	4			
Water for Engine	6	14	0			
Gas Fittings	56	17	0			
				152	13	7
— Tea and Coffee				30	2	6
— Library:—						
Books	120	18	11			
Periodicals	24	13	10			
Binding Books	127	11	1			
Council Gift	78	14	3			
Map-Cases	17	0	0			
				368	18	1
— Publication, Minutes of Proceedings				1,551	12	7
— Telford Premiums				195	12	9
— Manby Premium				10	14	3
— Miller Prizes				36	7	0
— Diplomas				24	15	7
— Manuscripts, Original Papers, and Drawings				21	10	1
— Annual Dinner (Official Invitations, &c.)				127	5	5
— Winding and Repairing Clocks				2	19	6
— Incidental Expenses:—						
Christmas Gifts	1	14	6			
Assistance at Ordinary Meetings	10	4	0			
Ditto at Students' Meetings	3	15	0			
Beating Carpets and Sweeping Chimneys	1	3	0			
Household Utensils, Repairs, and Expenses	81	5	0			
				98	1	6
— Legal Expenses				23	18	8
Carried forward				£5,702	4	1

ABSTRACT *of* RECEIPTS *and* EXPENDITURE

RECEIPTS—*cont.*

Dr.	£.	s.	d.	£.	s.	d.
Brought forward . .	463	9	7	8,397	10	10
To Institution Investments:—*cont.*						
Ditto, 1 Year, on £1,500, London, Brighton, and South Coast Ditto, Four and a Half per Cent. Debenture Stock	66	8	11			
Dividends, 1 Year, on £1,000, Manchester, Sheffield, and Lincolnshire Railway Four and a Half per Cent. Debenture Stock	44	5	11			
Ditto, 1 Year, on £1,344. 1*s.* 8*d.*, New Three per Cents	39	14	8			
				613	19	1
— Donations to Library				34	0	10
				£9,045	10	9
— Benevolent Fund				7	8	11
— Balance of Petty Cash, Nov. 30, 1873, due to the Secretary . .				16	4	7
				£9,069	4	3

from the 1ST DEC., 1872, *to the* 30TH NOV., 1873.

PAYMENTS—*cont.*

Cr.	£.	s.	d.	£.	s.	d.
Brought forward				5,702	4	1
By New Building:—	£.	s.	d.			
Decoration	865	0	0			
Furniture	190	0	0			
Upholstery and Carpets	322	1	4			
Architect	105	0	0			
				1,482	1	4
— Benevolent Fund Disbursements, 1873				9	7	10
— Telford Fund.—Balance of Income not yet expended in Annual Premiums, invested in £160. 18*s.* 5*d.*, Three per Cent. Reduced	149	5	1			
— Miller Fund.—Balance of Income not yet expended in Annual Prizes, invested in £165. 9*s.* 4*d.*, Three per Cent Reduced	153	9	5			
— Institution Investment:— £1,250, Great Northern Railway, Four per Cent. Debenture Stock	1,293	6	0			
				1,596	0	6
— Balance November 30, 1873, in the hands of the Treasurer				279	10	6
				£9,069	4	3

Examined and found correct.

(Signed) J. WOLFE BARRY,
ALFRED RUMBALL,
Acting for WM. LLOYD, } *Auditors.*
JAMES FORREST, *Secretary.*

December 3rd, 1873.

PREMIUMS AWARDED.

Session 1872—73.

The Council of The Institution of Civil Engineers have awarded the following Premiums :—

*1. A Watt Medal, and a Telford Premium, in Books, to Sir Charles Augustus Hartley, M. Inst. C.E., for his Paper on "The Delta of the Danube, and the Provisional Works executed at the Sulina Mouth."

2. A Telford Medal, and a Telford Premium, in Books, to James Deas, M. Inst. C.E., for his Memoir on "The River Clyde."

3. A Watt Medal, and a Telford Premium, in Books, to John Head, Assoc. Inst. C.E., for his Paper on "The rise and progress of Steam Locomotion on Common Roads."

4. A Watt Medal, and a Telford Premium, in Books, to William Anderson, M. Inst. C.E., for his Description of "The Aba-el-Wakf Sugar Factory, Upper Egypt."

5. A Telford Medal, and a Telford Premium, in Books, to William Thomas Thornton, C.B., for his Essay on "The relative advantages of the 5 feet 6 inches Gauge, and of the Metre Gauge for the State Railways of India."

6. A Telford Medal, and a Telford Premium, in Books, to Colonel William Henry Greathed, C.B., R.E., for his "Account of the practice and results of Irrigation in Northern India."

7. A Telford Premium, in Books, to John Milroy, Assoc. Inst. C.E., for his Paper on "Cylindrical or Columnar Foundations in Concrete, Brickwork and Stonework."

*8. A Telford Premium, in Books, to William Pole, LL.D., F.R.S., M. Inst. C.E., for his "Notes on the Rigi Railway."

*9. The Manby Premium, in Books, to Thomas Sopwith, Junr., M. Inst. C.E., for his Paper on "The Mont Cenis Tunnel."

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* Have previously received Telford Medals.

The Council have likewise awarded the following Prizes to Students of the Institution:—

1. A Miller Prize to Frank Salter, B.Sc., Stud. Inst. C.E., for his Paper on "Economy in the use of Steam."
2. A Miller Prize to John Newman, Stud. Inst. C.E., for his Paper on "The Calculations and Investigations necessary in designing Iron Cylinder Bridge Piers."
3. A Miller Prize to Alfred Fyson, Stud. Inst. C.E., for his Paper on "The English Standard Gauge versus Narrow Gauges for Railways."
4. A Miller Prize to Joseph Prime Maxwell, Stud. Inst. C.E., for his "Notes on Railway Curves."
5. A Miller Prize to Killingworth William Hedges, Stud. Inst. C.E., for his Description of "The Denver and Rio Grande Narrow Gauge Railway."
6. A Miller Prize to Nathaniel St. Bernard Beardmore, Stud. Inst. C.E., for his Account of "The Reconstruction of King's Weir on the River Lee."
7. A Miller Prize to Osbert Henry Howarth, Stud. Inst. C.E., for his Essay on "The Rationale of Permanent Way."
8. A Miller Prize to Charles Graham Smith, Stud. Inst. C.E., for his Paper on "Mortar."

Notice.

It has frequently occurred that, in Papers which have been considered deserving of being read and published, and have even had Premiums awarded to them, the Authors may have advanced somewhat doubtful theories, or may have arrived at conclusions at variance with received opinions. The Council would, therefore, emphatically repeat, that the Institution must not, as a body, be considered responsible for the facts and opinions advanced in the Papers or in the consequent Discussions; and it must be understood, that such Papers may have Medals and Premiums awarded to them, on account of the Science, Talent, or Industry displayed in the consideration of the subject, and for the good which may be expected to result from the discussion and the inquiry; but that such notice, or award, must not be considered as any expression of opinion, on the part of the Institution, of the correctness of any of the views entertained by the Authors of the Papers.

SUBJECTS FOR PAPERS.

Session 1873–74.

The Council of The Institution of Civil Engineers invite communications dealing in a complete and comprehensive manner with any of the Subjects included in the following list, and other Papers treating on analogous questions, such as—

a. Account of the Progress of any Work in Civil Engineering, as far as absolutely executed (Smeaton's Narrative of the Building of the Edystone Lighthouse may be taken as an example).

b. Descriptions of distinct classes of Engines and Machines of various kinds.

c. Practical Essays on Subjects allied to Engineering, as for instance, Metallurgy; and

d. Particulars of Experiments and Observations connected with Engineering Science and Practice.

List.

1. On the Application of Graphic Methods in the Solution of Engineering Problems, and in the Reduction of Experimental Observations.
2. On the Elasticity, or Resistance to Deflection, of Masonry, Brickwork, and Concrete, with observations on the Deflection of Bridge Piers, caused by the unequal loading of the Arches abutting on them.
3. On the Use of Concrete, or Béton, in large masses, for Harbour Works and for Monolithic Structures.
4. On the Manufacture of Iron and Steel as now practised; on the effect on the Strength and Tenacity of the Metal by the Admixture of Substances with the Ore; on the various Experimental Tests by which the Quality may be ascertained; and on the effects of Low Temperature on Metals.
5. On the Results of Experience in the recent Extended Use of Steel in Mechanism and in works of Engineering.
6. On the Theory and Practical Design of Retaining Walls for sustaining earth or water, and on Experimental Tests of the accuracy of the various theories.

7. On the Modern Methods of Constructing the Foundations of Bridges, and on Bridges of Large Span, considered with reference to examples; including an account of the Testing, and of the effects produced by Variations of Temperature.
8. On the different Systems of Swing, Lifting, and other Opening Bridges, with existing examples; and on the application of Machinery in working them.
9. On the Proportions and Details of Construction of Lock Gates, and on the application of Machinery for moving them.
10. On the Appliances and Methods for Rock-boring and Blasting, in this country and abroad, and on the results obtained.
11. On the Systems of Signaling on Railways, and on the comparative advantages of the absolute or permissive use of the Block System.
12. On the Constant Service of Water Supply, with special reference to its introduction into the Metropolis, in substitution for the Intermittent System; and on the waste of Water, and the best apparatus for its prevention.
13. On the various Modes of Dealing with Sewage, either for its disposal or its utilization.
14. On the Separate System of Sewering Towns, with a detailed description of the works in a town to which this system has been wholly or partially applied, and particulars as to the results.
15. On the Ventilation of Sewers, with a *résumé* of the Experiments as to the motion, pressure, &c., of Gas in the Sewers.
16. On the relative Value of Upland and of Tidal Waters in maintaining rivers, estuaries, and harbours.
17. On the Construction of Sluices, for the expeditious filling and emptying of Locks of large size, on navigable Canals.
18. On the Maintenance, by Sluicing, of the Harbours on the Coasts of France, Belgium, and Holland.
19. On the Sea Works at the mouths of the Rivers Adour and Maas, and on the effects produced thereby.
20. On Recent Improvements in the Construction of Steam Boilers adapted for very High Pressures.
21. On the best practical Use of Steam in Steam Engines, and on the effects of the various modes of producing Condensation.
22. On the modern Construction of Marine Engines, having reference to Economy of the Working Expenses, by Superheating, Surface Condensing, High Pressure, great Expansion, &c.

23. On Modern Locomotive Engines, designed with a view to economy, durability, and facility of repair, including particulars of the duty performed, of the cost of repairs, &c.
24. On the Application of Steam as a Motive Power for Pumping Water or Sewage, with a comparison of the advantages of different classes of Engines, and details of the cost of working for long periods.
25. On the various descriptions of Pumps employed for Raising Water or Sewage, and their relative efficiency; and on the employment of Water as a Motive Power for pumping, by means of Water-Wheels, Turbines, Water-Pressure Engines, or other Machines.
26. On the Employment of Steam Power in Agriculture.
27. On the Methods of transmitting Force to distant points; and on the Details of the existing systems of Rope Transmission.
28. On the Present State of Science in regard to the Manufacture of Gas for Illumination; and on the Materials most suitable for the purpose.
29. On the Manufacture of Mineral Oils, and the Lamps best adapted for their consumption in dwellings and lighthouses.
30. On the 'Output' of Coal in the United Kingdom, as compared with that of other countries, illustrated by statistical tables, plans, and diagrams, showing where Coal is produced, and where and how it is consumed.
31. On Mechanical Apparatus at present in use in 'getting' Coal.
32. On Modifications necessary in future Coal Mining Operations, suggested (or indicated) by the working of deep Coal-fields.
33. On Turf, or Peat, Cutting, Macerating, and Pressing Machinery, with experiments as to its heating power and expense as a Fuel, as compared with Coal.
34. On the various Methods of Draining distant isolated sections of Mines.
35. On Compressed Air as a Motive Power for Machinery in Mines, with some account of its application on the Continent.
36. On the Use of Diving Apparatus in Mines, especially in Westphalia and in Germany.

For approved Original Communications, the Council will be prepared to award the Premiums arising out of special Funds devoted for the purpose. They will not, however, consider themselves bound to make any award should there not be any communication of adequate merit; but, on the other hand, more than one Premium will be given, if there are several deserving memoirs on the same subject. It is to be understood that, in this matter, no

distinction will be made between essays received from a Member or an Associate of the Institution, or from any other person, whether a Native or a Foreigner.

The Communications should be written in the impersonal pronoun, and be legibly transcribed on foolscap paper, on the one side only, leaving a sufficient margin on the left side, in order that the sheets may be bound. A concise abstract must accompany every Paper.

The Drawings should be on mounted paper, and with as many details as may be necessary to illustrate the subject. Enlarged Diagrams, to such a scale that they may be clearly visible when suspended in the Theatre of the Institution, should be sent for the illustration of particular portions.

Papers which have been read at the Meetings of other Societies, or have been published in any form, cannot be read at a Meeting of the Institution, nor be admitted to competition for the Premiums.

The Communications must be forwarded, on or before the 31st of January, 1874, to the house of the Institution, No. 25, Great George Street, Westminster, S.W., where any further information may be obtained.

CHARLES MANBY, *Honorary Secretary.*
JAMES FORREST, *Secretary.*

THE INSTITUTION OF CIVIL ENGINEERS,
25, *Great George Street, Westminster, S.W.,*
31*st October*, 1873.

Excerpt Bye-Laws, Section XV., Clause 3.

"Every Paper, Map, Plan, Drawing, or Model presented to the Institution shall be considered the property thereof, unless there shall have been some previous arrangement to the contrary, and the Council may publish the same, in any way and at any time they may think proper. But should the Council refuse, or delay the publication of such Paper beyond a reasonable time, the Author thereof shall have a right to copy the same, and to publish it as he may think fit, having previously given notice, in writing, to the Secretary of his intention. No person shall publish, or give his consent for the publication of any communication presented and belonging to the Institution, without the previous consent of the Council."

ORIGINAL COMMUNICATIONS

RECEIVED BETWEEN DECEMBER 1ST, 1872, AND NOVEMBER 30TH, 1873.

AUTHORS.

Alleyne, Sir J. G. N., Bart. No. 1366.—On the Foundations of the Railway Bridges at Dordrecht and at Rotterdam.

Archibald, W. F. A. No. 1373.—The Ventilation of Sewers.

Banfield, E. No. 1372.—Railways in the Pampas of Buenos Ayres.

Blair, W. N. No. 1368.—The Rangitata Bridge, Canterbury, New Zealand.

Chabrier, E. No. 1379.—Notes on Asphalt, and on its various Applications.

Edwards, R. No. 1361.—On the different Systems of Road Traction Engines, with details of the results in each case.

Hartley, Sir C. No. 1367.—On the Changes that have recently taken place along the Sea Coast of the Delta of the Danube, and on the Consolidation of the Provisional Works at the Sulina Mouth.

Head, J. No. 1370.—On the Rise and Progress of Steam Locomotion on Common Roads.

Imray, J. No. 1355.—On the Interlocking of Railway Points and Signals.

James, J. W. No. 1374.—On the Driving of Piles to resist the Force that Ice is capable of exerting, tending to draw them from the Ground.

Kirk, A. C. No. 1364.—On the Mechanical Production of Cold.

Milroy, J. No. 1356.—Cylindrical or Columnar Foundations in Concrete, Brickwork, and Stonework.

Prestwich, J. No. 1358.—On the Geological Conditions affecting the Construction of a Tunnel between England and France.

Robinson, J. No. 1369.—On Modern Locomotives, designed with a view to Economy, Durability, and Facility of Repair.

Sanders, R. B. No. 1357.—Matters relating to the Profession of Civil Engineering.

AUTHORS.

Stoney, B. B. No. 1376.—On the Construction of Harbour and Marine Works with Artificial Blocks of Large Size.

Thornton, W. T. No. 1365.—The relative Advantages of the 5 feet 6 inches Gauge and of the Metre Gauge for the State Railways of India, and particularly for those of the Punjâb.

Willet, J. No. 1375.—On the Strength and Durability of Timber Bridges of Large Dimensions.

Wragge, E. No. 1359.—Description of the Toronto, Grey and Bruce, and Toronto and Nipissing Narrow-Gauge Railways in Canada; with some remarks on the Gauge of Railways.

LIST OF DONORS TO THE LIBRARY.

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Pain, A. C.; Phillips, J. A.; Pihl, C.; Pole, W.; Proprietors of —Adcock's Engineers' Pocket Book, Annales Industrielles, The Architect, Athenæum, Builder, Builders' Trade Circular, Engineer, Engineering, House Furnisher and Decorator, Iron Trade Circular, Iron and Coal Trade Circular, Journal of Gas Lighting, Revista Minera; Pye Smith, A.

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Turin; Royal Society of London; Royal Society of Edinburgh; Royal Scottish Society of Arts; Royal United Service Institution.

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United States Government; United States Patent Office; United States Naval Observatory; University of London.

Van den Bergh, —; Victorian Government.

Walker, R.; Warden of the Standards; Wex, G.; Whitworth, Sir J., Bart.; Wood, A. H.

Young, E.

CATALOGUE OF

ADDITIONS TO THE LIBRARY

FROM DEC. 1, 1872, TO NOV. 30, 1873.

IN CONTINUATION OF THE SUPPLEMENT TO THE SECOND EDITION OF THE CATALOGUE.

A.

A FIELD OFFICER. The joint education of the artillery and engineers injurious to the public service. 2nd edition. Tract. 8vo. vol. 229. *Lond.* 1873

ABBOT, H. L., Brevet Brigadier-General, U.S.A. Professional papers Corps of Engineers, No. 14. Siege artillery in the campaigns against Richmond, with notes on the 15-inch gun, including an algebraic analysis of the trajectory of a shot in its ricochets upon smooth water. 8vo. Plates. *New York*, 1868

ACADÉMIE ROYALE DE BELGIQUE. Centième anniversaire de fondation (1772–1872). 2 vols. 8vo. *Bruxelles*, 1872

ACHARD, A. Description d'une roue hydraulique avec arbre en tôle. Tract. 8vo. vol. 231. Cut. *Paris*, 1872

ADAMS, J. R. Dulwich college and the Endowed Schools' Commissioners. Tract. 8vo. vol. 229. *Lond.* 1873

ADCOCK'S Engineers' pocket-book, for the year 1873. 12mo. Cuts. *Lond.* 1873

AITKEN, R. Lectures. Canals, reservoir dams, &c. Delivered at the School of Military Engineering, Chatham. Folio. Plates and cuts. *Chatham*, 1872

ALDIS, C. J. B., M.D. General report on the sanitary condition of the Belgrave sub-district, parish of St. George, Hanover Square, and on the quality of the waters used therein. Tract. 8vo. Plate and map. *Lond.* 1856

AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE. Proceedings, 1848-59. 8vo. Plates, maps, and cuts. *Various places*, 1849–60

ANDREW, W. P. Break of gauge in India. Reports, &c. 2nd edition, containing a further report by Lieut.-Col. J. P. Kennedy, R.E. Tract. 8vo. vol. 227. Map. *Lond.* 1873

—— The Euphrates valley route to India. A paper read before the British Association at Brighton, in August, 1872, &c. Tract. 8vo. vol. 227. Map. *Lond.* 1873

ANONYMOUS. CANAL. Doab. Watercolour sketches of works. 2 vols. 4to. *No place*, 1832–38

—— DIAMOND DRILL. Tract. 8vo. vol. 233. Cuts. *New York*, 1871

—— ELECTRICITY. Rough notes of eleven lectures on the use of certain electrical apparatus. Tract. folio. Plates and cuts. *No place or date*

ANONYMOUS. Fisheries. Rules, orders, and ordinances for the fisheries, in Thames and Medway. Tract. 8vo. vol. 232. *Lond.* 1846

—— Irrigation. Irrigation in India: the present state of the question. Tract. 8vo. vol. 231. *Allahabad*, 1869

—— Lifeboats. An account of the efforts made by the council of the Society of Arts to ensure all ships having proper life-boat protection. Tract. 8vo. vol. 229. *Liverpool*, 1873

—— Local Government Act, 1858. Suggestions as to the preparation of plans, as to main sewerage and drainage, and as to water supply (corrected to 1872). Tract. folio. Plates and maps. *Lond.* 1873

—— Navigation. Rules and bye-laws for the regulation of the watermen and lightermen of the river Thames. Tract. 8vo. vol. 232. *Lond.* 1845

—— Railway. Eastern Counties, prospectuses relating to. Tracts. 8vo. vol. 228. *Various places*, 1834

—— —— K. K. priv. Erzherzog-Albrecht-bahn. Normalien, hochbau, oberbau, unterbau. 3 vols. folio. Plates. *No place*, 1872

—— —— London and Blackwall, prospectus. Tract. 8vo. vol. 228. Map. *Lond. no date*

—— —— Thames Haven railway: with observations on its anticipated advantages. Tract. 8vo. vol. 228. Map. *Lond.* 1835

—— —— The Board of Trade and the Kentish railway schemes. Tract. 8vo. vol. 228. *Lond.* 1845

—— —— The London, Chatham and North Kent (Independent), and the South-Eastern (Dover) railways. Tract. 8vo. vol. 228. *Lond.* 1845

—— Railways. Royaume de Suède. Atlas des constructions et du matériel des chemins de fer de l'état. Vol. 1. folio. Plates. *Stockholm*, 1870

—— —— Their uses and management. Tract. 8vo. vol. 228. *Lond.* 1842

—— River Danube. Plan der Donau-regulirung bei Wien. Tract. 4to. vol. 71. *Wien, no date*

—— Sewage. Suggestions for its utilization, having special regard to sanitary requirements. Tract. 8vo. vol. 232. Cuts. *Lond.* 1873

—— Water supply. Supply of water to London by means of the Henley and London waterworks and navigation. Tract. 8vo. vol. 231. Plate and map. *Lond.* 1848

ARCHER, W. H. Victoria. Patents and patentees. Vol. 5. Indexes for the year 1870. 4to. Plates. *Melbourne*, 1872

B.

BABBAGE, C. Table of logarithms of the natural numbers, from 1 to 108,000. Stereotyped edition. 8vo. *Lond.* 1872

BARNARD, J. G., Brevet Maj.-Gen., U.S.A. Professional papers of the Corps of Engineers, U.S.A. No. 22. Report on the North Sea Canal of Holland; and on the improvement of navigation from Rotterdam to the sea. 4to. Plates and maps. *Washington*, 1872

BARRETT, W. F. Elementary acoustics, and its application to the construction of buildings. Two lectures delivered to the Royal Engineers. Folio. Plates and cuts. *Chatham*, 1869

BARTLETT, W. H., AND OTHERS. Finden's views of the ports, harbours and watering-places of Great Britain. With descriptions, historical and topographical. 2 vols. 8vo. Plates. *Lond. no date*

BATTELY, Archdeacon. The antiquities of Richborough and Reculver. 12mo. Plate and map. *Lond.* 1774

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—— Railways in the United Kingdom and in India. Tract. folio. *Lond.* 1873

BELLAMY, C. J. Tables for the use of engineers and architects in taking out quantities of masonry, ironwork, &c. 8vo. *Lond.* 1873

BELGRAND. La Seine. Études hydrologiques. Régime de la pluie, des sources, des eaux courantes. Applications à l'agriculture. 8vo. Plates, maps and cuts. Folio. Atlas of plates and maps. *Paris*, 1873

BELVILLE, J. H. A manual of the barometer. 2nd edition. Tract. 8vo. vol. 229. Plate and cuts. *Lond.* 1849

BERNAYS, E. A. Lectures. Chatham dockyard extension works. Delivered at the School of Military Engineering, Chatham. Folio. Plates. *Old Brompton*, 1872

BERZELIUS, J. J. The use of the blowpipe in chemical analysis, and in the examination of minerals. Translated from the French of M. Fresnel, by J. G. Children. 4to. *Lond.* 1822

BINNIE, A. R. Description of the Nágpúr (Ambajhari) waterworks, with photographs, projected and carried out 1869–72. Folio. Plates. *Bombay*, 1872

BLACKFORD, W. W. Map and profile of the Virginia and Tennessee Railroad. Folding in tract. 8vo. *Richmond*, 1856

BLODGET, L. Climatology of the United States, and of the temperate latitudes of the North American continent, &c.

BOCCARDO, G. Fisica del globo. Spazi, climi e meteore, corso completo di geografia fisica e di meteorologia. 8vo. Plates, maps, and cuts. *Genova*, 1868

BONNIN, R. Note sur la construction d'une passerelle provisoire en bois établie à Andé, sur la Seine. 4to. Plates. *Evreux*, 1873

BOULT, J. Speculations on the former topography of Liverpool and the neighbourhood. Part. IV. The Mersey as known to the Romans. Tract. 8vo. vol. 233. *Liverpool*, 1873

BOURNE, J. An introduction to the second edition of railways in India. Tract. 8vo. vol. 228. Map. *Lond.* 1848

BRANDE, W. T. Outlines of geology. 12mo. Plates and cuts. *Lond.* 1829

BRESSE, —. Recherches analytiques sur la flexion et la résistance des pièces courbes, accompagnées de tables numériques pour calculer la poussée des arcs chargés de poids d'une manière quelconque, et leur pression maximum sous une charge uniformément répartie. 4to. Plates. *Paris*, 1854

BREWSTER, Sir D. Memoirs of the life, writings, and discoveries of Sir Isaac Newton. 2 vols. 8vo. Plates and cuts. *Edinb.* 1855

BRITISH AND FOREIGN RAILWAY LOCOMOTIVE ENGINE COMPANY. Prospectus. Tract. 8vo. vol. 229. *Lond.* 1847

BRITTEN, B. Pebble powder and cheaper guns. Tract. 8vo. vol. 229. *Redhill*, 1873

—— Rifled ordnance. Correspondence with the War Office. Tract. 8vo. vol. 229. *No place*, 1873

BROUGHTON COPPER COMPANY. Weight of seamless copper tubes. Tract. 4to. vol. 71. *Manchester, no date*

BURGES, A. Account of the old bridge at Stratford-le-Bow, in Essex. Tract. 4to. vol. 71. Plates. *Lond.* 1837

BURGH, N. P. Practical treatise on boilers and boiler-making. 4to. Plates and cuts. *Lond.* 1873

C.

CALVERT, J. C. Vazeeri Rupi, the silver country of the Vazeers, in Kulu: its beauties, antiquities, and silver mines. Including a trip over the lower Himalayah range and glaciers. 8vo. Map and plates. *Lond.* 1873

CAPPER, C. The port and trade of London, historical, statistical, local, and general. 8vo. *Lond.* 1862

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CATALOGUE des livres composant la bibliothèque de l'École des Ponts et Chaussées. 8vo. *Paris*, 1872

CEYLON. Flood. Report of Commission. Folio. *Colombo*, 1873

CIALDI, A. Avviso ai naviganti ed agl' idraulici sul Portosàido. Tract. 4to. vol. 71. Cut. *Milano*, 1872

COLLADON, D. Description de la terrasse d'alluvion sur laquelle est bâtie la ville de Genève. Tract. 8vo. vol. 253. Plate. *Genève*, 1870

—— Mémoire sur les effets de la foudre sur les arbres et les plantes ligneuses, et l'emploi des arbres comme paratonnerres. Tract. 4to. vol. 71. Plates. *Genève*, 1872

COLLIGNON, É. Traité de mécanique. 2e partie. Statique. 8vo. Cuts. *Paris*, 1873

COTELLE, —. Cours de droit administratif appliqué aux travaux publics. 3e édition. 4 vols. 8vo. *Paris*, 1859–62

COUCHE, C. Voie matériel roulant et exploitation technique des chemins de fer. 2 vols. 8vo. with 4to. plates. *Paris*, 1867, 1870
(Text and plates bound in two vols.)

COX, E. T. Third and fourth annual reports of the geological survey of Indiana, made during the years 1871 and 1872. 8vo. Plates and cuts. 8vo. atlas of maps. *Indianopolis*, 1872

CRACE-CALVERT, F. Experiments on the oxidation of iron, with appendices. Tract 8vo. vol. 233. *Manchester*, 1872

CRAMER, J. A. Elements of the art of assaying metals. 8vo. Plates. *Lond.* 1744

CRAWFORD, R. Report upon the proposed Transandine railway, to connect Buenos Ayres with Chile, by a line over the Planchon pass. Tract. 8vo. vol. 227. *Buenos Ayres*, 1872

CROOKES, W. On the manufacture of beet-root sugar in England and Ireland. 8vo. Plates and cuts. *Lond.* 1870

CUNNINGHAM, A., Major-General, R.E. Archæological survey of India. Four reports made during the years 1862—63—64—65. 2 vols. 8vo. Plates and maps. *Simla*, 1871

D.

D'ALEMBERT, — Traité de l'équilibre et du mouvement des fluides, pour servir de suite au traité de dynamique. 4to. Plates. *Paris*, 1770

DAY, St. J. V. On some evidences as to the very early use of iron. Tract. 8vo. vol. 233. Plate and cuts. *Edinb.* 1873
(Second Communication to the Philosophical Society of Glasgow.)

DE LESSEPS, F. Percement de l'isthme de Suez. Atlas des cartes, plans, sondages, profils et forages à l'appui du projet de la Commission Internationale. 3e série des documents. 4to. *Paris*, 1856

DE MARCOARTU, A. On the application of acoustic, optical, electric and maritime telegraphy to navigation and meteorology. Tract 8vo. vol. 229. *Bradford*, 1873

DEBAUVE, A. Manuel de l'ingénieur des ponts et chaussées. Machines. 8vo. Plates and cuts. *Paris*, 1872

DEUTSCHER ARCHITECTEN UND INGENIEURE. Bericht über die XIV. versammlung, abgehalten am 30, 31, August, 1 und 2 September 1864 zu Wien. 4to. Plates and cuts. *Wien*, 1865

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January, 13, 1874.

THOMAS E. HARRISON, President,
in the Chair.

The following Candidates were balloted for and duly elected :— William Smith, as a Member; Arthur Turnour Atchison, M.A., Stud. Inst. C.E., Arthur Lloyd Cochrane Bamber, Stud. Inst. C.E., Edward Bazalgette, Stud. Inst. C.E., George Horatio Townsend Beamish, Stud. Inst. C.E., Walter Chapman Burder, Stud. Inst. C.E., William Gordon Lynch Cotton, Charles Edward Cowper, Stud. Inst. C.E., Jacob Forrest, William Gill, John Ellard Gore, Richard Fuge Grantham, John Alfred Griffiths, Stud. Inst. C.E., Richard Lionel Jones, B.A., Robert Nuttall, William Lancaster Owen, George James Perram, Stud. Inst. C.E., George Pothecary, John Somerville, and Allen Anderson Whitehorne, as Associates.

It was announced that the Council, acting under the provisions of Sect. III., Cl. 8, of the Bye-Laws, had transferred Frederick Collier Christy, George Frederick Deacon, John Lawton Haddan, George Albert Hutchins, Alexander Leslie, James Mansergh, Henry Prince, and William Vawdrey, from the class of Associate to that of Member.

Also, that the following Candidates, having been duly recommended, had been admitted by the Council, under the provisions of Sect. IV. of the Bye-Laws, as Students of the Institution :— John George Blackett, Clarence Arthur Cramer, George James Atchison Danford, Henry Evan Griffith Evans, John Coleman Fergusson, Charles MacIntyre Forbes, Thomas Percy Gunyon, John James Hatten, Arthur Cameron Hurtzig, John Pollard, Oswald Milton Prouse, Percy Thursby, Charles Henry Billinhurst Whitworth, and John Henry Williams.

Mr. Harrison addressed the Meeting in the following terms, on taking the chair for the first time, after his election as President:—

Gentlemen,

I have to thank you most sincerely for placing me in the honourable position of your President, and I promise that, while I occupy this chair, my best endeavours shall be exerted to increase the prosperity and usefulness of the Institution. I feel confident of your support in promoting the harmony and interest of the meetings, and I trust that Papers will be contributed on the numerous subjects of interest, to the Engineering profession and to the public, and that the visitors who attend the meetings will lend their aid in thoroughly discussing them.

In considering the subjects to bring before your notice this evening, I looked over the addresses of my predecessors in this chair, and I recommend their study to all young engineers. Sir John Rennie, in 1846, gave a most complete narrative of the rise and progress of Engineering in all its branches in this country; and the Presidents who followed him have continued, within certain limits, the history of Engineering up to the present time, by accounts of various important works in different parts of the world executed by British engineers.

Civil Engineering is now one of the acknowledged standard professions; its growth has been rapid within the last one hundred years, and more particularly within the last half century; the Royal Charter of Incorporation of this Institution dating only from 1828.

Smeaton, a name dear to all Engineers, will always be looked upon as the founder of the profession; whilst Telford, the first President of this Institution, and John Rennie, will be known to posterity by the important works which they executed throughout the kingdom. The first great impetus, however, to general Engineering in this country must be dated from the invention of the steam engine by Watt, about one hundred years ago. At a later period the more rapid strides have been due to the improvement of the locomotive engine, and the consequent development of railways, by the late George Stephenson, who may be justly called the father of the railway system, and whose career was so nobly emulated by his son, Robert Stephenson. There can be no doubt that for some years past railways have been the means of employing a larger number of the members of the profession than any other

branch of engineering, and the public is in consequence rather apt to regard them as almost the only means of employment for young engineers. There are, however, in the profession openings suited to every degree of talent, and constant opportunities for the profitable investment of capital.

The objects of the establishment of this Institution are fully and forcibly set forth in the Royal Charter of Incorporation, and are described as being "for the general advancement of Mechanical Science, and more particularly for promoting the acquisition of that species of knowledge which constitutes the profession of a Civil Engineer, being the art of directing the great sources of power in nature for the use and convenience of man, as the means of production and of traffic in States both for external and internal trade, as applied in the construction of roads, bridges, aqueducts, canals, river navigation, and docks, for internal intercourse and exchange; and in the construction of ports, harbours, moles, breakwaters, and lighthouses; and in the art of navigation by artificial power for the purposes of commerce; and in the construction and adaptation of machinery; and in the drainage of cities and towns."

No more useful, more comprehensive, or more noble objects could be set before any body of men; and, up to this time, these duties have been most fully and ably discharged, the trade and commerce not of this kingdom alone, but of the whole world, having been thereby materially promoted and developed. It is a singular fact that in the above enumeration of the objects of Civil Engineering, though written so lately as the year 1828, the word "railway" does not appear.

I purpose presently directing attention to the wide fields which are developing, in order to give encouragement to young engineers just entering on their professional career. I say to them, Do not be disheartened if you do not at once find employment. In my own case, after completing my term of pupilage under the late Mr. W. Chapman, I came to London to seek employment, bringing a letter of introduction from that gentleman to Mr. Telford. He received me most kindly, and when I had explained the objects of my visit, he said, "Young man, you have made a great mistake in choosing civil engineering for your profession, and the sooner you turn your attention to something else the better, for there are very few who rise to eminence, all the work is centred in them, and the rest have little or nothing to do." For twelve months I was cast down, and thought what he said was only too true; but I then made the acquaintance of my dear friend,

the late Mr. Robert Stephenson, and was employed by him in taking the levels from Wolverton to Rugby, for the first application to Parliament for the then London and Birmingham railway. From that time I have been constantly and actively employed. I was in June 1834, nearly forty years ago, only a few months before the death of Mr. Telford, elected a Member of this Institution, and there are now only twenty-three Members on the books whose date of election is prior to my own.

Let me here say a few words on the education of young engineers. Mr. Fowler, in 1866, made this subject the chief feature of his Address, and he sketched an able and elaborate programme for the guidance of those intending to follow the profession. It is, however, quite clear that no rigid rule of general application can be laid down, and the means and opportunities of obtaining the necessary education must vary in almost every case. No one will regret having had a University career, if it be within his reach; but under any circumstances a liberal education, embracing a knowledge of mathematics and the applied sciences, is indispensable, and an acquaintance with chemistry and geology is becoming every day more useful and important. In the case of an engineer intending to devote himself to mechanical engineering exclusively, a regular apprenticeship to that branch of the profession is a necessity; and to the engineer who purposes following the more general branches of the profession, a practical acquaintance with mechanical work, whenever it can be obtained without too much time being devoted to it, will always be found advantageous. I would strongly urge the young student to make himself a master of accounts, for a knowledge of bookkeeping, which I accidentally attained when young, has proved to be one of the most useful lessons I ever learned. The course of study at King's College is an excellent example for a young man to follow before entering an engineer's office. But success will depend, as in every other profession, on the young man himself; and if during his pupilage he shows a determination to master his profession, and attends closely to his duties, he will establish a character which will be certain to aid him at every step in his future career.

Although in England the employment arising from the construction of railways is not so great as it has been, there is still a large amount of work to be done, to meet the increased requirements of the traffic of the country; and in foreign countries this branch of practice will for a long time demand the attention of the rising generation of engineers.

Railways in India are still in their infancy: but the Indian

government has devised a comprehensive scheme for the construction of a system several thousand miles in extent.

The concession lately granted by the Shah of Persia to Baron Reuter, for the construction of engineering works in Persia, whether carried out in their entirety or not, must open out entirely new ground.

In Egypt, extensive basins and graving docks have recently been completed and connected with the general railway system at Suez; and at Alexandria, harbour and dock works, commenced by our late lamented Past President, Mr. McClean, are being carried on with vigour. In Lower Egypt, the railway system has been greatly extended during the last twelve months, especially by the works of a new "relief line" on the left bank of the Nile, from Cairo to near Alexandria; whilst in Upper Egypt the railway is being steadily pushed on up the left bank of the Nile to the south; and a further extension into the Soudan or Central Africa is contemplated. After an elaborate survey by English engineers, under the direction of Mr. Fowler, Past President, and a full report by that gentleman, the line, from the First Cataract to Khartoom, has been commenced, and will ultimately be carried to the Red Sea, with the object of affording a speedier route for the Indian mails. Whilst opening out a new country on its route, and with the aid of the White Nile, which is being dredged and improved, the districts of Soudan and Fatiko, described by Sir Samuel Baker as being well suited for the growth of cotton, sugar, and coffee, will be brought into cultivation. But it is not only to railways that the Khedive has devoted his attention. He contemplates extending the irrigation of the Lower Nile, and completing and utilising the Barrage itself. Irrigation canals, both in Upper and in Lower Egypt, are generally receiving great attention. On the sugar estates of the Khedive, a system of light railways for conveying the sugar canes to the mills has been executed with complete engineering and financial success. All these works are under the guidance of Mr. Fowler, Past President, as Consulting Engineer to the Khedive. It is hoped that his report and experiments on the minimum flow of water in the Nile, as also the report which it is understood has been made, in conjunction with Mr. F. J. Bramwell and Dr. Letheby, on the manufacture of sugar in Egypt, will in due time be communicated to this Institution.

In South America, Mr. Bateman, one of our Vice-Presidents, is now executing at Buenos Ayres water, drainage, and sewerage works, and a new harbour will soon be commenced. The city,

which has a population of between 180,000 and 200,000 persons, is on the southern bank of the River Plate, a fresh water river of upwards of 30 miles in width. The present water supply and drainage are so defective, that when, about three years ago, the place was visited by yellow fever, it was reported that upwards of one-tenth of the gross population was carried off. Warned by that visitation, it has been determined to take measures for remedying the evils under which the city suffered. The water of the River Plate, which is fit for all purposes of domestic consumption, will be used for the general supply. At a distance of 3½ miles above the city a shaft will be sunk into the bed of the river, 900 yards from the shore, where the water is 12 feet deep, to a depth of 30 feet below the bottom of the river, which consists of an impervious clay. From the bottom of this shaft a tunnel will be driven under the river to the bank, and thence for a distance of 3½ miles to the pumping station of the existing water-works, where additional and extensive pumping power will be provided. A complete system of depositing and filtering tanks, and a high-service covered reservoir to contain 16,000,000 gallons, will be provided, and arrangements will be made for an immediate supply of 8,000,000 gallons a day, and for doubling that quantity when necessary. These works are now under contract, and the total cost will be about £1,000,000 sterling.

In the drainage works, one of the most difficult questions was how to deal with the storm waters. After ascertaining approximately the maximum volume of sewage to be dealt with, Mr. Bateman decided to divide the sewers into three classes, viz. :— 1st. Collecting sewers to convey both the ordinary sewage of small districts and the heavy rainfalls of 1½ inch per hour. 2ndly. Intercepting sewers, to receive the sewage from the collecting sewers, and ¼ inch per day of the rainfall they may be conveying. Anything beyond this combined quantity will flow over side weirs into wells, or chambers, which will receive the flood or storm water, and deliver it into conduits, which will carry the flood waters of heavy rainfalls direct to the river. The contemplated outlay on the drainage and sewerage works, already under contract, amounts to about £1,000,000 sterling.

It is further intended to construct extensive docks, to avoid the great expense and delay which now take place in sending goods from vessels to the shore, the cost of lighterage often exceeding the whole freight to or from Europe. It is proposed to form an embankment 5,000 yards in length, and from 18 feet to 20 feet in height, so as to inclose about 550 acres, which will be available

for docks, or other commercial or public purposes. There is to be an entrance basin of 18 acres, and a dock 2,700 yards in length, 230 feet in width, and 20 feet in depth at low water, with every possible convenience. To approach this dock a sailing channel, 12 miles long, will be dredged over a width of from 150 to 200 yards, to a depth of 21 feet at low water. Results ascertained by the construction of an experimental channel have satisfied a special commission that the proposed channel can be executed and maintained at a reasonable cost, and there seems now to be no impediment to carrying out this great work, the estimated cost of which is about £2,500,000, whilst the direct saving to the country is calculated at £1,000,000 sterling per annum, besides that which will result from preventing the damage, delay, and depredation of the existing system.

It will thus be seen that the Argentine Republic is contemplating an outlay at Buenos Ayres on engineering works of about four and a half millions sterling. But the government is not confining its enterprise to these works alone, as, under the control of Mr. Edward Woods, Member of Council, nearly 250 miles of railway have been completed, and 120 miles more are now in progress.

The Peruvian government also is constructing about 500 miles of railway, and the Chilian government about 300 miles, Mr. Woods in both cases acting as the Consulting Engineer in England.

The development of railways in Brazil, since the completion of the Sao Paulo line, and its subsequent successful working, has been very great, and branches are in course of extension in all directions. In 1867 the total length of railways in operation in that empire was 420 miles, and in 1873 it had reached 637 miles, the capital expended on them being about £12,000,000. At present there are nearly 1,000 miles in course of construction, and surveys are in progress for about 1,500 miles more. In the neighbouring State of Uruguay, 40 miles are opened for traffic, 38 miles more are nearly completed, and 200 miles are in course of construction, at an average cost of £10,000 per mile. The total length of railways conceded in Uruguay is about 330 miles. For these extensive works, as well as for many of those in Brazil, Mr. Brunlees, Member of Council, is the Engineer-in-chief.

The Empire of Japan has only recently been opened to the western world. The late revolution in that government has determined a remarkable change in the policy of the empire. The old exclusiveness has been abandoned, and an intention has been manifested to adopt and take advantage of the scientific know-

ledge and mechanical improvements of Western civilisation. Public works have already been undertaken on a considerable scale, and there is a prospect of their being more extensively developed hereafter. Accurate statistics of the empire are still wanting, but it appears certain that the country offers great inducement for the establishment of engineering works. The extent of the empire is about 170,000 square miles. It is densely populated, containing many cities, said to exceed in size any British towns except the metropolis. The climate is excellent; the people are intelligent, clever, and enterprising; and the country is believed to be rich in mineral productions. The Japanese government has invited co-operation in enabling them to carry out works of improvement. Loans to the amount of three millions have been raised for this purpose in England, and, as a security, the management of the expenditure has been vested in parties representing the bondholders. The first work undertaken was a railway 20 miles in length to connect Yedo, the capital city of the empire, with the commercial port of Yokohama. It was opened in October 1872, and, although only coaching traffic has yet been carried, the receipts already average about £100 per mile per week. The line is now being doubled, and another of about the same length will be opened immediately to the port of Kobe, where a screw pile pier is being built to allow the largest steamers to come alongside; and further lines are in progress, or under survey, to the extent of several hundred miles. Our new Member of Council, Dr. Pole, acts as the Engineer in England to the Japanese government, and Mr. Boyle, C.S.I., formerly of the East Indian railway—and so well known for his gallant defence of the station at Arrah during the Indian Mutiny—assisted by a numerous staff of English engineers, is the Resident Engineer-in-chief.

China, with its untold millions of population, hesitates to avail itself of the advantages to be derived from the introduction of railways; but it is impossible to imagine that this can continue long. When once the prejudice has been overcome, and even a few miles of railway have been made, the advantages will become too apparent to be neglected, and China will afford ample ground for the exercise of engineering skill.

Other extensive works, in progress in different parts of the world, deserve notice—some for their magnitude, others for the novelties attending them. One of the largest is the Amsterdam Ship Canal, which is being executed under the direction of Sir John Hawkshaw, Past President, in conjunction with

Mr. Dirks, of Amsterdam, as the engineers, and Messrs. H. Lee, and Sons, of Westminster, as the contractors. Amsterdam was for centuries one of the great commercial centres of Europe; but latterly its trade suffered, in a great measure, from vessels of increased tonnage being unable to reach the city owing to the shallow sea approaches. To remedy this evil the North Holland Ship Canal, 52 miles in length from Lake IJ to the Helder, was completed in 1825, through the low lands of North Holland, with 18½-feet depth of water; but, although extensively used, it eventually proved inadequate to meet the rapid increase of trade fostered by the introduction of railways throughout Europe, which made it imperative for Amsterdam to provide still better communication with the North Sea. The distance from Amsterdam to the sea in a direct line is only about 15½ miles, the intervening space being occupied by two shallow fen lakes, and a belt of sand about 3 miles wide, which protects that part of Holland from the inroads of the sea. This is the route which has been chosen for the new Amsterdam Ship Canal. The works consist of a harbour in the North Sea, formed by two piers, each about 5,000 feet long, inclosing a sheltered area of 260 acres. The width of entrance is 850 feet. The canal is entered by a complete arrangement of large locks about ¾ mile from the North Sea, and at the opposite end a dam across Lake IJ, ⅘ mile in length, excludes the waters of the Zuider Zee; and in this dam another complete set of locks is placed. For building these last-named locks, a circular cofferdam of 525 feet internal diameter was constructed, and ten thousand bearing piles were used in the foundations. The banks of the canal through the lakes are 38½ miles long, the channel being dredged to a depth of 23 feet, with a bottom width of 89 feet. Extensive pumping machinery is erected for the purpose of keeping the surface water of the canal at a fixed level below high-water mark. The pumps are capable of discharging nearly 2,000 tons of water per minute lifted 9 feet 9 inches, or 2,700 tons per minute when the lift is 3½ feet. A novel mode of dredging has been adopted; the material falling from the buckets of the dredger is delivered into a vertical cylinder, in which a "Woodford" pump revolves, and being there mixed with a sufficient quantity of water to reduce it to a semi-fluid state, it is forced by the pump through a line of wooden tubes, connected by leathern joints, floating on the surface of the water, and passing on to the banks, where the stream of mud is deposited. In this sketch, I have avoided giving details of the mode of construction adopted, as I hope we may receive a full descriptive account of the whole work, which is at once

interesting and novel, particularly as regards the mode of forming the dams and embankments.

There is, perhaps, no more wonderful instance of the rapid development of commerce than that afforded by the port of Liverpool, which has kept pace with the trade it has been called upon to accommodate. The Mersey Dock Board some years ago purchased, at the northern end of Liverpool, a large extent of foreshore, which they have been gradually reclaiming, whilst also acquiring property at the southern end. During the last session of Parliament they obtained powers to construct on these lands a complete system of docks, with additions to their existing graving docks, as well as some of Mr. Edwin Clark's hydraulic docks, with shed accommodation on a larger scale than any previously built. The estimated cost of these works exceeds £4,000,000. All the works at Liverpool are executed in the most substantial manner. No more instructive lesson could be offered to the student than an examination of the finished works, and those in course of construction, under the direction of our Member, Mr. Lyster.

Liverpool is not alone, however, in admitting the necessity of further dock accommodation. Almost every port in the Bristol Channel is extending its docks, and on the Clyde, at Hull, and at Hartlepool large additions are being made; whilst on the Tyne, besides large docks about to be commenced, the works of river improvement which have been for several years in progress are being pushed forward with vigour. In all these cases the additional accommodation has been turned to account by a corresponding increase of traffic. It may be said, in fact, that there is scarcely a port on the coasts of Great Britain that is not feeling the necessity of doing something to meet the increasing trade; so that docks and harbours will form an important branch of civil engineering for some years to come.

At Newcastle, Mr. Ure, M. Inst. C.E., is building a roadway swing bridge over the River Tyne, which for its width and weight will be the largest ever executed in England. It is hoped that he will shortly fulfil his promise of giving to the Institution an account of this structure, as well as of the very successful works which he has carried out for improving the River Tyne.

Mr. Bouch, M. Inst. C.E., is constructing an iron bridge over the estuary of the Tay above Dundee, which is now rapidly progressing towards completion. It is by far the largest structure of the kind that has been built, and I know of no engineering work embracing more points of interest and novelty, both in itself and in the appliances used in its construction. The ingenuity

shown by the contractors in meeting all the difficulties they have had to contend with deserves the highest praise. The bridge will be 10,320 feet long, having eighty-nine spans of various widths, fourteen of them of 200 feet each, passing over the navigable channel of the river, with a clear headway of 88 feet above high water, the piers being founded at a considerable depth below the surface of the water. Mr. Bouch, however, is not satisfied with the magnitude of this bridge, but he has determined to earn for himself the title, if I may be permitted to perpetrate a pun, of "Pontifex Maximus," for in the last session an Act of Parliament was obtained, under his supervision as Engineer, for the construction of a bridge over the Firth of Forth. As the railway companies interested in the traffic which will pass over it are prepared to guarantee an annual sum, equal to paying interest on the estimated cost, there is every probability that the work will soon be commenced. The total length of the bridge from shore to shore will be about 8,000 feet, with two centre spans of 1,600 feet each, and a series of small spans on either side. There will be a clear headway under the two large spans of 150 feet above the high-water mark, and the centre pier, which will partly stand on an island in the middle of the estuary, will measure from the foundation to the summit 680 feet. The large spans are to be a combination of the suspension and the girder system, steel being the material used.

But whilst English engineers are executing or designing works such as I have briefly described, our brother engineers on the Continent and in America have been carrying out works vieing with any we have done, from many of which we may learn most useful lessons.

In Holland, iron bridges, extending up to about 400-feet span, are quite common. The railway bridge recently completed at Moerdyk deserves especial mention, consisting as it does of fourteen spans of 328 feet each, and a swing bridge of 164-feet opening. I wish, however, to direct your attention to the process which is there adopted of treating the iron, to prevent oxidation. The iron having been prepared for riveting, is first put into a bath of dilute muriatic acid for about twelve hours, and when taken out is thoroughly washed with pure water to remove the acid. It is then put into a second bath of lime-water, in which it is turned over and scrubbed to free it from rust or scale. It is next transferred to another bath of boiling water, in which it remains until it gets as hot as the water, and when taken out is in a moment dry and ready to receive a coating of hot linseed oil

put on as quickly as possible. After this process it is riveted at once, or painted with red lead if it is to be sent away.

The International bridge over the River Niagara, connecting the railway systems of Canada and the United States in the neighbourhood of Buffalo, was commenced in 1870, and opened for public traffic in November 1873. A full account of this work, by Mr. S. Gzouski, with detailed drawings, is now in the library of this Institution. The total length of the bridge is 3,651 feet. Across the main channel there is a swing bridge, on a pivot pier, with two openings of 160 feet each, the length of the swing being 364 feet; it is worked by steam power, and can be opened or shut in sixty seconds. There is also a smaller swing bridge, with two openings of 90 feet each, the largest of the other spans being 248 feet. The greatest depth of water in which the piers were founded was 48 feet; but as the current of the river runs from 6 to 12 miles an hour, according to the direction of the wind, and as ice fields the full width of the river, and from $\frac{1}{2}$ mile to 1 mile long, pass down, an idea may be formed of the difficulties of constructing the works.

In subaqueous foundations we have only to refer to the East River Bridge, between New York and Brooklyn, with its foundations at a depth of 78 feet below the level of mean high water, and its centre suspension span of 1,600 feet, or to the Saint Louis Bridge over the Mississippi, with its foundation 100 feet below the surface of the water, and its three spans of 500 feet with extensive land arches, and we see at once designs full of boldness and novelty, and a power of invention among American Engineers equal to any emergency.

The blowing up of the Blossom Rock in the Harbour of San Francisco, a full account of which, with detailed drawings, by Colonel Williamson and Lieutenant Heuer of the United States Service, has been presented to the library of this Institution, is another instance of engineering resource. This rock, the top of which was only about 5 feet below the surface at mean low water, was in the track of vessels entering the harbour. Its greatest length at the depth of 24 feet was 195 feet, its greatest breadth at the same depth was 105 feet, and the quantity of rock to be removed, to obtain a depth of 24 feet of water, was 5,000 cubic yards. Mr. Von Schmidt, the contractor for the work, sank a shaft in the top of the rock, and undermined the area to be removed, excavating a chamber equal to the cubic contents of the crust of the rock, which during the progress of the work was supported by timbers. He next introduced 43,000 lbs. of gunpowder, skilfully

distributed throughout the chamber, and water was let in to act as a tamping. The powder was then exploded, and a column of water, variously estimated at from 200 to 300 feet high, and about 200 feet in diameter, rose majestically in the air, intermingled with rocks and pieces of timber, the broken crust of the rock falling back into the excavation. The comparatively trifling quantity of rock remaining was afterwards easily extracted, and the operation was a complete success.

Whilst on the subject of Californian works, the project of our Member, Mr. R. M. Brereton, for utilising the waters of the Tulare Lake, should be mentioned. This consists of a system of canals in the great Joaquin Valley, for the purpose of irrigating the adjacent lands, for the transport of passengers and freight, and ultimately for supplying water to the towns and cities of the state. Lake Tulare has, at lowest water, an area of nearly 700 square miles, at an elevation of 200 feet above the level of the sea. By the line of the canal, of which nearly 40 miles are executed, it will be about 230 miles distant from San Francisco. On these works it is calculated that about £2,000,000 sterling will be expended, and a large tract of fertile land will be brought into cultivation.

Pure water has been obtained for the supply of Chicago by driving a tunnel nearly 2 miles under Lake Michigan, and then putting a shaft down into the tunnel.

The railway tunnel, about 4½ miles long, through the Hoosac Mountain is nearly approaching completion; and the St. Gothard Tunnel, the length of which will be about 9 miles, is in active progress. These works are of no ordinary magnitude, and great interest attaches to them all.

The use of concrete is still comparatively in its infancy, and the time may be looked forward to when it will be much more generally employed for engineering works; but the great rise which has taken place in the price of cement has retarded its adoption. Sir John Coode, Member of Council, has lately introduced it in the case of a breakwater pier at the port of Douglas, in the Isle of Man, where a considerable length of the work, under low water of spring tides, has been formed by putting down concrete in mass, within timber frames fixed upon the rock in the bottom of the bay. By this mode of proceeding, the slow and expensive process of levelling the rock, to receive the masonry, has been entirely obviated, and the union of the work with the bed of rock on which it is constructed has been perfect. The deepest portion thus founded was in 16 feet of water at low water

of ordinary spring tides, and the largest block formed in this manner weighed about 300 tons.

Upon "La Corbiére,"—a dangerous rock lying off the south-west extremity of the island of Jersey,—the same engineer has just completed a lighthouse tower of concrete made with the stone of the immediate locality and with Portland cement. This tower is about 50 feet in height, with an internal diameter of 11 feet. It is believed to be the first structure of the kind erected entirely with this class of material.[1]

Probably no branch of the profession has made greater progress within the last ten years than Telegraphic Engineering. Telegraphy was, for some time after its adoption on railways, confined chiefly to internal communication between the principal places of business in this and other civilised countries; then to some comparatively short lines of submarine communication between our shores and the coasts of France, Belgium, and Holland, and a few lines in the Mediterranean. The longest line that was next successfully carried out was the Malta and Alexandria Submarine Telegraph Cable, laid in the year 1861, regarding which Papers were read before this Institution by Mr. C. W. Siemens, Member of

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[1] In a subsequent communication from Mr. David Stevenson, M. Inst. C.E., of Edinburgh, it is stated that so long ago as 1854 a lighthouse tower was built at North Unst in Shetland, composed entirely of stone shivers obtained on the rock, set in cement, which, so far as he knew, was the first application of such materials to the construction of lighthouse towers, and many beacons had since then been built on the Scotch coasts of the same materials. The following was an extract from his Report to the Commissioners of Northern Lighthouses, as to North Unst, dated the 29th of September, 1854.

"The works which have been executed consist of a tower of rubble masonry, 21 feet in height, built of stones, quarried on the rock, set in Roman cement. The woodwork of the timber lightroom, prepared at Leith, was built into the upper part of the tower, and the whole was surmounted by a cast-iron lantern which was prepared in Edinburgh. The dwelling-houses adjoin the tower, and are formed of corrugated iron, surrounded by a wall of rubble stones set in Roman cement. Behind the houses stands the cast-iron water tank, which is 10 feet square, and 4 feet deep, and is capable of containing 2,500 gallons of water. The tank is likewise surrounded and protected by rubble walls set in cement. In order to procure shelter for the buildings and insure stability, they were sunk below the general surface of the rock, and there is a descent of six steps to the court which intervenes between the houses and the tower."

Mr. Thomas Stevenson, in a letter to "Nature," in August 1871, proposed to apply the same mode of construction to lighthouse towers founded on tide-covered rocks, such as the Bell Rock, or the Chickens, now in progress off the Isle of Man; but this mode of construction had not been adopted for lighthouse towers in such situations, although, as above stated, it had been used for tide-covered beacons.

Council, and Mr. H. C. Forde, M. Inst. C.E.[1] The knowledge and experience gained in the construction of these early works have led up to Telegraphic Engineering as it exists at the present day, and which is now represented by a special Institution, "The Society of Telegraph Engineers," numbering about 500 members, who, by the permission of the Council, hold their meetings in these rooms. It may fairly be stated that nearly every town and village of importance has its telegraph as well as its post office, and the national consequence which telegraphy has thus assumed has resulted in the taking-over of the service by the Government, in Great Britain, in India, and in all Continental countries. International telegraph conventions are held triennially, for the settlement of momentous questions. Whilst the advantage of telegraphic communication is thus brought within the reach of the public generally on moderate terms, great companies have taken the initiative in establishing cables across the Atlantic and other oceans, and in putting India into speedy communication with the mother country. The communication with India is particularly interesting, inasmuch as it is carried on by two separate companies, one having established a submarine cable, and the other a land line through Germany, Russia, and Persia. Both undertakings being worked with a view to the attainment of the highest practical results, the utmost care is taken in their supervision, and they furnish fair tests of what is attainable by each system of insulated wire.

The telegraphic instruments employed give proof of extraordinary inventive activity. The difficulty in sending messages to great distances without intermediate breaks appears to have been completely conquered, since messages are flashed across the Atlantic Ocean by means of the reflecting instrument invented by Sir William Thomson, and when Kurrachee in India can be reached nearly instantaneously by the means of Siemens' Double Relay system. The type printing instrument by Hughes, the automatic instrument by Sir Charles Wheatstone, and other inventions, contribute powerfully to the extension and certainty of telegraphic communication; while the magnetic instrument, dispensing with the necessity of batteries, renders it easily applicable for private purposes. A method of working through one wire simultaneously in both directions was brought forward about twenty years ago—before the time was ripe for the adoption of such a step; but it

[1] *Vide* Minutes of Proceedings Inst. C.E. vol. xxi., p. 49 *et seq.*

has now been taken up again with what appears to be considerable success.

For the working of railways the electric telegraph has become a necessity, as without it the block system could not be carried out, and there are still many uses on railways to which it is applicable. Railway managers and railway engineers may look with confidence to the cordial co-operation of their brethren, the Telegraphic Engineers, in promoting its further employment.

Having been for forty years continuously in the habit of attending Parliamentary committees, it is impossible for me to avoid contrasting the Parliamentary practice of my early experience with that which now exists. In every point of view the result is in favour of the present practice. I trust that the system of having a Court of Appeal to a Committee of the House of Lords from the decisions of a Committee of the House of Commons will never be altered. Not that I find fault with the decisions of the Committees of the House of Commons on the evidence laid before them; but I have known numerous cases where circumstances have unexpectedly arisen which it was impossible at the moment to go into, but which, when fully sifted before a second Committee, have entirely altered the features of the case, and led to a reversal of the previous decision, thus avoiding the commission of an unintentional injustice.

Having also for many years been connected with the working as well as with the making of railways (though for a long time I have ceased to take an active part in the details of the actual working), and having for a few years acted as a General Manager, I may refer to some of the points affecting railways, which have lately been discussed in the public journals.

It is too much the custom to assert that railway directors and railway managers and officials have no feeling, and that they look to a saving of expenditure in preference to providing for the public safety. Now I have no hesitation in saying that a more ungenerous and unjust charge was never made against any body of men. I believe the public have no idea of the anxieties felt by all who are connected with railway management. I have seen Directors completely overcome on receiving a report of a railway accident; and after the few years' experience I had as a railway manager, nothing would have induced me to continue in the office. So far from these gentlemen deserving the character attributed to them by the public, they ought to receive the greatest sympathy. I could name many men whose early deaths, or permanent ill

health, may be traced to the laborious work they have had to undergo in the service of the public, and to the constant anxieties incident on their duties. Instead of economy governing the actions of Directors, I say, from my own experience, that when it is clearly shown to them, by their responsible officers, that the adoption of any improvement will tend to promote the safety of the public, they do not hesitate to accept it.

There is also a "popular delusion" which I think ought to be corrected. The public believe that the various recommendations made to the railway companies from time to time by the officers of the Board of Trade, such as the block system, interlocking of points, &c., are really inventions of those officers; whereas the fact is that not one of these systems or inventions, or any new idea in connection with the working of railways, has ever really been suggested by them.

The railway companies also are at a great disadvantage with the public in respect to the reports which are from time to time made by the Government inspecting officers—their dictum is never questioned by the public; and although railway officers of great experience constantly differ from those officials in the conclusions at which they arrive, the railway companies feel that any appeal against these reports is useless, and practically judgment is allowed to go by default.

In making their reports, the officers of the Board of Trade are in the position of *ex post facto* judges. I need hardly point out that there is a great difference, to use an expression of our late President, Mr. Hawksley, between looking into the events of the week that is past, and looking into the middle of next week. Should the country at any time become the purchasers of the railways, these officers will soon find the change in their position when the responsibility of working the lines devolves upon them.

Captain Tyler, in his valuable Report on Railway Accidents in 1872, says: "Whatever be the amount of care taken, the item of human fallibility will still remain, and will always be the cause of a certain number of accidents." And he states that in 180 cases of accidents out of 238, "negligence, want of care, or mistakes of officers, were apparent." This is a subject to which for years past I have devoted a great deal of attention and anxious thought, and I attach much more importance to the item of "human fallibility" than Captain Tyler appears to do. It is an undoubted fact that accidents frequently occur in the hands of the most experienced men in a moment of forgetfulness, and many instances of such cases might be quoted. An accident occurred under the block

system owing to the momentary forgetfulness of the signalman, who was the person selected, in consequence of his superior intelligence and experience, to instruct the other signalmen in their duties. Some years ago an important chief officer on the North-Eastern railway, who, for twenty years, was in charge of the building of a class of wagon called the 'Chaldron wagon,' pointed out that the tops of these wagons came so close together that any one standing on the soles might be jammed between them, and he recommended that the soles should be lengthened. The order was given, but within a few weeks he was killed in the very manner which he had suggested might happen, though no man knew the danger better than he did.

I was myself nearly killed, twenty years ago, by stepping past the end of the station wall at Darlington without looking out whether there was any engine coming in the other direction. It happened that there was, and I was caught by the engine buffer and knocked several yards. Now, if I had been thinking only of the railway, I should have known the danger of doing what I did. This is not wilful negligence, but a momentary forgetfulness such as all are liable to, and which has been and ever will be the cause of many railway accidents. Accidents are constantly occurring to railway servants employed in shunting wagons, and I believe that hydraulic power may be advantageously used in large shunting yards, as a substitute for locomotives and horses, and with considerable economy and less danger to the shunters.

It may be considered as settled that the block system will, as soon as it is possible to complete the necessary works, be introduced throughout the whole of the railways in England; but this will at once increase that element of danger—"human fallibility"—to a large extent. In the case of the North-Eastern railway it is calculated that, on the completion of the block system, the number of signalmen will be increased from five hundred to two thousand, thus augmenting in the same ratio the risks of "human fallibility."

There is an undoubted tendency on the part of enginemen and other railway servants to believe (and it is only human nature that they should do so) that all these arrangements of the block system and additional signals do, in fact, provide for their safety. Consequently they do not keep the same look out, or use the same care that they would do on a line apparently less protected; and that this is the case observation and inquiry have clearly demonstrated.

I do not intend by this to argue against the introduction of

the block system; but when it is put forward as a perfect security to railway travelling, I wish to point out that it introduces another important element of danger, generally much underrated, and to state that when railway officials may have appeared to be slow in recommending to their Directors the adoption of the block system, the circumstances just mentioned are those which have chiefly influenced them.

A Paper on the subject of the working of the block system, when it has been more fully tested on a large scale and on lines of considerable traffic, would be of much interest, and would no doubt lead to a practical discussion of great service.

The question of the effect of the labour market on railways, both in their construction and working, has come forcibly home to every one connected with them. It is not too much to say that all new works are now costing from 30 to 40 per cent. more than they did a few years ago, and nearly double the time is required to complete them—whilst where works are not near large towns it is hard to get men at all—and as a rule they do not accomplish the same amount of work as they formerly did.

The difficulty of enforcing discipline is becoming constantly greater, as "dismissal" is no longer a punishment, when employment can at once be had elsewhere; and a reprimand is constantly met with the reply, "Oh! very well, I'll go." I have found that nothing attaches men more to the service of a railway company than giving them comfortable cottages, with gardens to cultivate.

In the important colliery and iron districts of the North of England the labourers have an objection to night work—such as emptying the wagons at the furnaces or filling coke, after a certain hour, at the coke ovens, and pitmen limit their work in many cases to four days a week. This creates a great difficulty in getting traffic carried, and will, if continued, necessitate an enormous increase in rolling stock, sidings, and engine power, for in many cases the work got out of a mineral wagon in these districts is little more than two-thirds of what it was three or four years ago.

The rapid development of traffic on all railways is very remarkable. On the North-Eastern railway, with only 77 additional miles opened, the gross receipts have risen in the last five years from £3,871,000 in 1868 to £5,930,000 in 1873, or an increase of upwards of £2,000,000, or more than 50 per cent. This additional traffic, combined with the action of the men in limiting their hours of work, with the introduction of the block system, has necessitated a remodelling of the old lines of railway in the district, which will occupy a long time in completing.

On the general question of the policy of railway companies towards the public, I have always advocated the greatest liberality, especially in giving increased facilities and accommodation,—in the reduction of fares in populous districts, and in rendering every encouragement to persons able and willing to develop the industry of the country; and after watching the effects of this policy in many important cases, I am not aware of any instance in which it has not been successful.

As to the policy of railway companies towards each other, though not an advocate for unlimited and indiscriminate running powers, I should not hesitate to interchange or grant running powers whenever it can be shown that public convenience will be promoted by it. I would also allow the company exercising these powers to carry local passengers, receiving a small percentage for the service.

The institution of the Railway Companies Association, originally suggested by Mr. Thompson, the Chairman of the North-Eastern Company, calling together, from time to time, the Directors of the different companies on any matter of general importance, has had a beneficial effect in promoting a good feeling between railway directors. I have no doubt that it has also promoted, on the part of the "General Managers," a broader view of the identity of interest which unquestionably exists between the Railway Companies and the public, and I trust that this feeling will continue to increase.

In conclusion, allow me to thank you again for the honour you have done me by electing me to the proud position of President of this Institution. I enter on the office with a full sense of the importance and responsibility of the duties I have undertaken, and I again promise you that my earnest endeavours shall be used to discharge those duties in the best interests of the Institution; and when my term of office expires, I hope I shall have so fulfilled this promise, that you will not find any reason to regret the confidence you have reposed in me.

Being duly moved and seconded, it was—

RESOLVED—That the President be requested to permit his Address to be printed and circulated with the Minutes of Proceedings.

January 20, 1874.

THOMAS E. HARRISON, President,
in the Chair.

No. 1,364.—"On the Mechanical Production of Cold." By ALEXANDER CARNEGIE KIRK, Assoc. Inst. C.E.[1]

BY the mechanical production of cold, as distinguished from cooling by radiation or conduction, the Author would, in the following Paper, be understood to mean the removal of heat from a body by a continuous circle of mechanical operations, without the use of anything colder than the body it is desired to cool. He will chiefly confine himself to a description of apparatus, in which the medium used is an incondensable gas, such as atmospheric air.

Every machine for producing cold, under the conditions stated, is simply the negative solution of a motive-power heat engine. A motive-power heat engine absorbs heat at a high temperature, rejects it at a lower temperature, and developes an amount of power in proportion to the number of degrees through which the temperature falls. A machine producing cold is such an engine, absorbing heat at a low temperature, rejecting it at a higher temperature, and requiring work to be spent in driving it in proportion to the number of degrees through which the temperature is raised. Heat in falling from a high temperature to a lower temperature exerts "work"; and "work" has to be expended to raise a low temperature to a higher temperature. The thermo-dynamic formulæ for every heat engine apply equally to the corresponding refrigerating machine; the work in the former appearing as a positive, and in the latter as a negative quantity. It is a condition, equally of a motive-power engine and of a refrigerating machine, that the temperature at which heat is rejected should be high enough to be abstracted by surrounding bodies—in practice water; and thus this

[1] The discussion upon this Paper occupied portions of two evenings, but an abstract of the whole is given consecutively.

temperature is much higher in tropical countries than at home. The most familiar motive-power engine, the steam engine in its most complete form, becomes a refrigerating machine, the water in the boiler being evaporated nearly in vacuo, and condensed at something over the atmospheric pressure. Harrison's well-known ether machine is the same; ether being substituted for water on account of its lower evaporating point, by which temperatures as low as zero in the Fahrenheit scale can be reached. This may serve as an illustration of machines for cooling purposes in which condensable vapour is used.

Similarly, any engine, such as Ericcson's air engine, or Stirling's, using an incondensable gas may become a refrigerating machine; expansion by heat and compression combined with cooling serving the same purpose as evaporation and condensation in the former case. The first has been often tried as a practicable refrigerator. The second may be taken as the type of those to be described in this Paper.

As a medium, incondensable gas allows an infinite range of temperature to be used, but accompanied by a large amount of mechanical friction; for the net result in power is the difference between two large powers, each attended by its own proper friction, the sum of which is the friction of the machine. A condensable gas, on the other hand, is limited in the range of temperature, but the friction is simply that due to the power developed.

The Author having now explained, he hopes with sufficient fulness, the general conditions of all machines for producing cold by mechanical means, will proceed to the consideration of those machines in which any incondensable gas may be employed, though in practice he has confined himself to the use of atmospheric air. His attention was first seriously directed to this subject while manager of the paraffin oil works, at Bathgate, of Messrs. Young, Meldrum and Binny. To extract the solid paraffin, a very valuable product contained in solution in the heavier portions of the oil, it is necessary to cool down all that portion of the oil to a temperature of 35° to 40° Fahr., in order to cause the paraffin to crystallise, and drain off the oil or liquid part from the paraffin crystals. When the works were in their infancy, this was accomplished by storing this portion of the oil during summer, and exposing it in flat dishes to the cold of winter. As the works increased, store tanks were added; until the loss attending the keeping of a valuable material all through the summer in an unmarketable state, and the difficulty of working up such an accumulation in a few months of winter, rendered it necessary to devise means to enable the paraffin

to be separated, and the products made available all the year round.

The first practical step in this direction was the erection, in the spring of 1861, of one of Harrison's ether machines. This did good service for a year, but was found to be too small. Moreover, the use of so inflammable a substance was objectionable and dangerous, especially as the machine was worked not only by day, but also at night, when the same supervision could not be maintained.

As it was felt to be a matter of importance to avoid repeating the risks that had already been run, and to obtain, if possible, a machine more adapted to ordinary men, the Author was requested by Messrs. Young and Meldrum to investigate the subject thoroughly, with a view to find a substitute for ether as a cooling medium. Atmospheric air was selected as the most promising, being safe and inexpensive, and capable of yielding powerful cooling effects; but considerations of safety chiefly determined the selection.

Before attempting anything on a large scale, the Author searched for information as to what had been already done in this direction. Not being able to learn more than that Dr. Gorrie had constructed a machine that produced ice in Florida, and that a similar one made in London had failed, he commenced a series of experiments on a small scale. Following the method adopted in these early attempts, he first tried the plan of compressing air into a receiver, allowing it next to lose by conduction the heat generated by compression, and then expanding it by making it do work in driving an engine like a high-pressure steam engine. To effect this he used a compressing pump, discharging the air into a large coil of lead pipe, which acted as an efficient receiver and cooler of the compressed air. A model of a steam engine was altered so as to expand the air by which it was driven about three times, and this was connected to the other end of the coil of pipe. Although the small engine was driven by the compressed air, there was no cooling of the escaping air; and although a larger engine was then employed, and the compressing pump was worked by power, there was still disappointment. The air ought to have been cooled, and doubtless would have been to some extent, in a large machine; but it was apparent that there must be great imperfection in the nature of the apparatus, or otherwise cooling would have taken place, even in an apparatus on a small scale. The principal defect was, that at every fresh stroke the air entered the expanding cylinder at the tempera-

ture of the surrounding atmosphere, thus neutralising much of the cooling effect of the preceding stroke. Combined with this there was also moisture in the air,—to remove which no precaution had been taken,—and the great amount of conduction in a small apparatus,—where the surfaces exposed, though carefully protected with felt, are much larger in proportion to the weight of air at work than in a large machine. These failures, added to the difficulty of arranging a simple and efficient method, by which the cool escaping air, having done its work, might spend the rest of its cold in cooling the compressed air preparatory to its entering the expanding cylinder, and the practical difficulties foreseen in working a piston air-tight under low temperatures and high pressures, caused the idea to be abandoned.

Attention was next turned to a machine allied to Stirling's air engine, for as it was considered to be by far the best air engine yet produced, it was thought it ought to make a good cooling machine. A model having been made on this plan, for the first time cold was produced by the expansion of air. In this machine the temperature was lowered to about 8° Fahr., but, after many modifications and reconstructions, mercury and paraffin oil spirit were frozen with it. This apparatus consists of an air-compressing pump with the delivery valve removed; the suction valve remaining in its place and serving to admit air when, by leakage, the pressure falls below that of the atmosphere. The outlet of the pump is connected by a piece of tin pipe to a cylinder (Plate 10, Fig. 1), A B C D, of the thinnest tin plate, 5 inches in diameter, the ends being cones, A B E F and C D G H both looking inwards. The upper cone is open above, and into it is placed the body to be cooled; while the lower cone is closed at the bottom, and supplied with cold water, entering by the pipe I and flowing off by the pipe K, to carry off the heat generated by the compression of the contained air. G H L L is the pipe connecting the interior of the tin cylinder with the compressing pumps, soldered into the top and bottom of the lower cone, and having on it a well, M, containing sulphuric acid, to remove the moisture of the air. N N is a piston, formed like the cylinder of the thinnest tin plate, with conical ends to fit those of the cylinder, but allowing a stroke of $1\frac{1}{4}$ inch, the ends of the cones being connected by a circular opening. The whole is soldered air-tight, filled with dry sawdust, and lapped round with greasy flannel to make it work in a manner air-tight; the passage by which the apices of the cones are united is filled with wire gauze O in layers, and a small rod P is attached and passes through a stuffing-box at L, by which the piston is moved

up and down. This rod is worked by an eccentric, placed at right angles to the cranked axle of the pump, which is single-acting.

The action of the apparatus is as follows: The pump, on its downward stroke, expels the air by the pipe L, connected to the orifice from whence the delivery valve has been removed, and compresses the air in the cylinder A B C D to nearly double its previous tension. On the up stroke the air previously expelled is drawn back, and the air remaining in the cylinder A B C D expands to its previous pressure, or to double its volume. The number of double strokes is about 120 a minute. The piston N N is moved by the eccentric, placed at right angles to the crank by which the pump plunger is actuated. While the pump plunger is compressing the air, the piston is nearly stationary at the top of its stroke, and while the pump plunger is moving upwards, the piston N N is nearly stationary at the bottom of its stroke, the air contained in the cylinder being compressed in the space between the piston and cylinder bottom, and expanded in the space between the piston and cylinder top. During the time that the piston N N, which may be called the displacing piston, is moving up or down, the air passes through the regenerator O, which, by retaining and giving out heat, permits the passage of the air without the passage of heat from one space to the other, however much the one may be colder or hotter than the other.

Thus, when the machine is in action, the contained air is in a state of alternate compression and expansion, the part in the passages L L forming a cushion for transmitting the compression and expansion to the air contained in the cylinder A B C D, and being alternately heated and cooled without giving out or receiving heat; while the part in the cylinder A B C D is compressed in the space under the piston N N, shifted through the regenerator by its motion, and expanded in the space thus formed above the piston; the air is shifted again by the upward motion of the piston and regenerator, and compressed in the lower space, and so on. While the air is compressed in the lower space, the heat generated is removed by the water flowing through the cone; and while the air is expanding in the upper space, heat is abstracted from whatever has been placed in the upper cone to be cooled. By the action of the regenerator, if it were perfect, the air would be returned to each chamber at the temperature at which it left it, and would commence both its heating and its cooling from that temperature. Thus, if no heat were abstracted at the lower end, and no heat supplied at the upper, the temperature of the lower

end would continually rise, and that of the upper end continually fall, the power required to drive the machine continually increasing as the resistance to compression increased and the assistance got from expansion diminished.

Practically there is a limit to this, since whatever be the material of the apparatus, ultimately such a difference of temperature between the hot and the cold ends will be attained, that sufficient heat will be conducted through the piston and cylinder from the hot end to supply the heat absorbed at the cold end. The Author believes that in this model, notwithstanding it is made of thin metal to prevent internal conduction, and is protected from external conduction by a thick lining of dry wool inclosed in a tight case, this limit is reached, probably 20° below the temperature of freezing mercury, as mercury is sufficiently frozen to admit of being hammered by a wooden mallet into a square bar before melting. The paraffin spirit in which the mercury was placed, at the same temperature, is a creamy, slightly gelatinous substance.

Indeed, the only limit to the temperature attainable is the conducting power of the material of which the apparatus is composed, and the imperfections of the regenerator, which in the model was certainly too small for such a great range of temperature. Had a larger model been used, or had air of a higher density been employed, the loss by conduction would have been less, as in either case the weight of working air would have borne a higher ratio to the section of metal available for conduction.

One difficulty in working with dry air, which showed itself in these experiments, is to get a sufficiently extensive heating or cooling surface, and to cause the air to move over it in such a way as to bring every particle into contact with the surface, for the absorbing and conducting power of dry air is so small that nothing short of bringing each particle in contact with the surface to be cooled is of much avail. This was one reason for adopting the deep conical ends, simplicity forbidding any complicated arrangement of tubes or the like. Still there is no doubt the temperature of the working air is, at one end, much below freezing mercury, and, at the other, much above the water used to cool it.

Having got thus far, the Author proceeded with the working drawings of a large machine. While these were being made, a series of experiments was commenced to determine what loss attended the action of regenerators of various kinds, a point on which no reliable data could be found. For this purpose an apparatus was fitted up consisting of a cylinder A B of tin plate (Plate 10, Fig. 2), 6 inches in diameter, and with a length of stroke of $3\frac{1}{8}$ inches. On

one end of this cylinder there was a chamber, D, through which a slight current of steam of the atmospheric pressure was passed, in order to maintain a constant temperature of 212°, while on the other end a chamber, C, was fitted with a thermometer, and filled at the commencement of each experiment with water. To prevent conduction of heat from the hot to the cold end, the middle of the cylinder was surrounded by a water jacket, F F, through which a stream of water of the same temperature as that put into the chamber C continually flowed. To prevent the temperature of the room from affecting the water contained in the chamber C, the whole of the cylinder, from the water-belt, including the chamber C, was inclosed in a wooden box filled with dry sawdust. A tap, G, allowed the water to flow away at the end of each experiment. The piston was of thin tin plate soldered air-tight, also filled with dry sawdust, and it was moved backwards and forwards by a small rod, H, passing through a stuffing box, and connected to a crank driven by the steam engine. In the centre of the piston a hole 3 inches square received the regenerators, O, to be tested. The apparatus was fitted up in a room of which the temperature was maintained at 60° as nearly as practicable.

The method of procedure was to pass the steam of the pressure of the atmosphere through the chamber D, let water run through the belt F, fill the chamber C with a measured quantity of water of the same temperature, set the piston A B in motion, and keep it working for fifteen minutes. The air passes through the regenerator, from the cold to the hot end, and back, once in each stroke, and the number of degrees the water in C rose in temperature was noted. In order that the pistons and the regenerator might attain a fair working temperature, on starting a series of trials the first one was always rejected. To maintain a pressure above the atmosphere, a small pipe was attached to a compressing pump, and the pressure regulated by a gauge connected to the hot end. The quantity of water contained in C was 8,300 grains, and the volume of air moved through the regenerator was 88·3 cubic inches. To find the amount of conduction of heat from the hot to the cold end, the machine was allowed to stand for fifteen minutes without moving the piston, when the water in C was warmed 1°·3.

In the following tables, in the first column is given the number of experiments made; in the 2nd the average temperatures of the water at commencing; in the 3rd the average temperatures at the conclusion of each experiment; in the 4th the average number of double strokes made per minute; in the 5th the duration

of the experiments; in the 6th the pressure of the air above the atmosphere in lbs. per square inch; in the 7th these results are reduced, showing the degrees by which the air is warmed during one double stroke, or in its passage from the cold to the hot end and back again. The temperature of the hot end is taken at 212°, and that of the cold end as the mean between the temperatures at the commencement and the end of the experiments, the difference of these giving the mean range of temperature through which the air passes. The specific heat of air is taken at 0·238 as under constant pressure. In column 8 the results in column 7 are divided by the range of temperature the air passes through from the cold to the hot end, giving the amount by which the air is warmed per double stroke for 1° difference of temperature; or, in other words, the loss per degree of difference of temperature between the hot side of the regenerator and the cold.

Experiment No. 1.

Regenerator consisted of sixty-seven layers of brass wire gauze, twenty-nine meshes per inch, and each $2\frac{7}{8}$ inches × $2\frac{7}{8}$ inches.

1	2	3	4	5	6	7	8
	°	°		mins.	lbs.	°	°
10	55·5	59·3	54·3	15	0	3·856	0·0249

Experiment No. 2.

Regenerator composed of seventy-seven pieces of the same gauze as No. 1, $2\frac{7}{8}$ inches × $1\frac{3}{8}$ inch, half the space being blocked up, thus giving half the area of air passage in No. 1.

1	2	3	4	5	6	7	8
	°	°		mins.	lbs.	°	°
11	53·7	58·3	53·7	15	0	5·231	0·0335
6	53·2	60·0	56·0	15	10	5·015	0·0323
3	53·3	61·5	56·0	15	15	5·244	0·0339
8	53·4	61·9	56·0	15	20	4·692	0·0304

Experiment No. 3.

The same as No. 2, speed nearly doubled.

1	2	3	4	5	6	7	8
	°	°		mins.	lbs.	°	°
4	49·5	56·5	115·0	15	0	4·218	0·0272
5	51·2	60·9	113·2	15	10	3·785	0·0243
6	51·8	63·2	116·0	15	15	3·705	0·0240
6	53·7	66·1	114·7	15	20	3·531	0·0232

Experiment No. 4.

Regenerator composed of tin plate cut in strips, laid edge to edge, and connected into one sheet by two narrow strips soldered across them. By cutting the sheet in strips conduction is prevented. These sheets were packed so as to present their edges to the passing air, being kept apart by the strips soldered across. Of these sixty filled the space in the regenerator, and were used.

1	2	3	4	5	6	7	8
	°	°		mins.	lbs.	°	°
8	56·0	60·5	57·0	15	0	4·777	0·0310

Experiment No. 5.

Regenerator as in No. 4, but composed of only twenty-seven plates or sheets, occupying half the 3-inch square hole in the piston; that is, 3 inches × 1½ inch.

1	2	3	4	5	6	7	8
	°	°		mins.	lbs.	°	°
5	54·4	60·3	56·0	15	0	6·992	0·0452
5	50·0	58·7	56·8	15	10	6·654	0·0422
5	51·6	61·7	56·0	15	15	6·688	0·0431
6	51·0	61·7	56·0	15	20	6·123	0·0393

Experiment No. 6.

Regenerator the same as above, twenty-seven plates; speed nearly doubled.

1	2	3	4	5	6	7	8
	°	°		mins.	lbs.	°	°
7	50·7	60·4	116·0	15	0	6·159	0·0394
6	43·7	56·6	113·3	15	10	5·229	0·0323
4	44·8	60·0	116·0	15	15	4·952	0·0310
4	52·2	69·4	116·0	15	20	4·999	0·0330

Experiment No. 7.

Apparatus used previously, altered by lengthening the cylinder and piston, the diameter and length of stroke remaining the same. Piston 6 inches deep, hole in the centre 3 inches square; size of sheets, made in the same way as in No. 4, $5\frac{1}{4}$ inches $\times$ $2\frac{7}{8}$ inches; number of plates, as in No. 5, twenty-seven, and, as in that experiment, half of the hole in the piston blocked up.

1	2	3	4	5	6	7	8
	°	°		mins.	lbs.	°	°
4	51·2	61·5	116	15	0	6·603	0·0424
4	52·2	66·4	115	15	10	5·729	0·0375
3	55·0	70·3	116	15	15	5·136	0·0344
3	47·7	65·0	116	15	20	5·032	0·0324

Experiment No. 8.

Regenerator composed of sixty-two sheets arranged as in No. 7, $5\frac{1}{4}$ inches $\times$ $2\frac{7}{8}$ inches.

1	2	3	4	5	6	7	8
	°	°		mins.	lbs.	°	°
4	49·5	56·8	115·0	15	0	4·441	0·0279
4	53·5	65·1	115·5	15	10	4·554	0·0298
4	53·7	67·4	114·0	15	15	4·629	0·0306
3	54·0	69·8	116·0	15	20	4·560	0·0304

Experiment No. 9.

Regenerator composed of forty-nine solid plates of zinc, $5\frac{1}{4}$ inches $\times$ $2\frac{7}{8}$ inches, weighing $\frac{1}{2}$ lb. per square foot, parted by very narrow strips of the same, and completely filling the hole in the piston.

1	2	3	4	5	6	7	8
	°	°		mins.	lbs.	°	°
3	50·3	61·1	114·7	15	0	7·049	0·0451
3	55·5	69·8	114·7	15	10	5·788	0·0388
3	53·0	69·2	114·7	15	15	5·528	0·0366
2	53·0	71·5	114·0	15	20	5·500	0·0368

Experiment No. 10.

The pieces of gauze used in No. 3 were replaced in the original short cylinder, the apparatus carefully examined, and the experiment repeated.

1	2	3	4	5	6	7	8
	°	°		mins.	lbs.	°	°
5	49·6	56·2	115·2	15	0	3·915	3·0246
5	51·2	60·9	113·6	15	10	3·775	0·0242
5	51·2	62·6	118·0	15	15	3·642	0·0235
6	53·7	66·1	114·7	15	20	3·530	0·0232

Experiment No. 11.

The same pieces of gauze used in No. 10 were arranged to cover the whole space in the piston, 3 inches square, forming a regenerator 3 inches square and $1\frac{1}{2}$ inch thick, double the area and half the thickness of the last.

1	2	3	4	5	6	7	8
	°	°		mins.	lbs.	°	°
5	53·8	60·7	117·6	15	0	4·054	0·0262
3	51·3	61·8	114·7	15	10	4·097	0·0263
3	52·3	63·8	116·0	15	15	3·742	0·0243
4	54·0	66·5	114·0	15	20	3·585	0·0236

Experiment No. 12.

Repetition of No. 1; the same apparatus and regenerator; sixty-six layers.

1	2	3	4	5	6	7	8
	°	°		mins.	lbs.	°	°
5	54·0	59·1	116·0	15	0	2·787	0·0179
4	53·0	61·9	113·5	15	10	3·420	0·0221
4	55·2	65·1	107·0	15	15	3·421	0·0225
3	55·0	65·7	112·0	15	20	3·062	0·0202
3	55·0	67·2	114·7	15	25	3·034	0·0201

Experiment No. 13.

Apparatus and gauze the same as in No. 12, except that twenty-two layers of gauze were removed, leaving forty-four layers in the piston.

1	2	3	4	5	6	7	8
	°	°		mins.	lbs.	°	°
4	51·0	56·6	116·0	15	0	3·154	0·0199
4	50·2	58·4	99·5	15	10	3·542	0·0225
3	50·0	59·7	100·0	15	15	3·575	0·0227
3	50·0	60·7	108·0	15	20	3·173	0·0203
3	50·0	62·0	114·7	15	25	3·034	0·0194

Experiment No. 14.

Apparatus and gauze the same as in No. 12, except that forty-four pieces of gauze were removed, leaving twenty-two layers in the piston.

1	2	3	4	5	6	7	8
	°	°		mins.	lbs.	°	°
4	50	56·8	114·5	15	0	4·089	0·0258
4	50	59·4	111·0	15	10	3·711	0·0236
4	50	61·6	114·5	15	15	3·828	0·0245
4	50	62·8	116·0	15	20	3·490	0·0224
3	50	64·2	115·3	15	25	3·571	0·0231

Experiment No. 15.

Apparatus the same as No. 12, but a finer gauze used, viz., twenty-two layers, with ninety meshes per inch, $2\frac{7}{8}$ inches $\times$ $2\frac{7}{8}$ inches.

1	2	3	4	5	6	7	8
	°	°		mins.	lbs.	°	°
4	50	56·9	116·0	15	0	4·110	0·0259
4	50	53·9	114·5	15	10	3·391	0·0215
3	50	60·7	114·0	15	15	3·510	0·0224
4	50	62·5	114·5	15	20	3·569	0·0229
4	50	63·0	114·5	15	25	3·261	0·0210

Experiment No. 16.

Apparatus the same as No. 12, with twenty-two pieces of gauze, $2\frac{7}{8}$ inches $\times$ $2\frac{7}{8}$ inches, with sixty threads per inch.

1	2	3	4	5	6	7	8
	°	°		mins.	lbs.	°	°
4	50	56·2	113·0	15	0	3·692	0·0232
3	50	59·5	116·0	15	10	3·611	0·0230
4	50	61·8	116·0	15	15	3·852	0·0247
4	50	63·0	115·0	15	20	3·712	0·0239
3	50	63·7	116·0	15	25	3·412	0·0220

Experiment No. 17.

Apparatus made to resist higher pressures with a new cylinder of cast iron, bored, but of the same diameter as the cylinders of tin previously used, with a water-belt and chambers at the ends as before. The piston was used as in former experiments, having the same length of stroke, but the sawdust was removed, leaving the whole space to be filled by the regenerator.

Regenerator composed of thirty circular layers of brass-wire gauze, $5\frac{1}{2}$ inches in diameter, with sixty meshes per inch.

1	2	3	4	5	6	7	8
	°	°		mins.	lbs.	°	°
1	67·0	71·5	116·0	15	0	2·349	0·0164
1	65·0	71·0	116·0	15	10	2·069	0·0144
1	67·0	73·0	116·0	15	20	1·478	0·0104
1	66·0	73·5	116·0	15	40	1·241	0·00872
1	66·0	74·0	116·0	15	60	·9836	0·00693
3	64·7	73·0	114·7	15	80	·8121	0·00567
3	66·7	75·8	115·3	15	100	·7512	0·00534

EXPERIMENT No. 18.

Apparatus and regenerator as in No. 17, except that forty pieces of gauze were used.

1	2	3	4	5	6	7	8
	°	°		mins.	lbs.	°	°
2	62·5	67·0	114·0	15	0	2·390	0·0162
2	62·5	67·25	113·0	15	10	1·560	0·0106
2	61·5	67·5	116·0	15	20	1·478	0·01002
2	63·5	70·5	112·0	15	40	1·182	0·00815
2	62·5	71·5	113·0	15	60	1·160	0·00800
2	61·0	70·5	116·0	15	80	·9502	0·00649
4	59·5	67·2	113·5	15	100	·6261	0·00421

The experiments are given in the order in which they were tried, and may be divided into two series. The first, to No. 9 inclusive, was made in order to ascertain whether regenerators of gauze or of plates should be preferred. The advantage being in favour of gauze, the experiments on plates were not pursued further. The second series was confined to ascertaining the best proportions for a regenerator composed of gauze.

From these experiments the following deductions may be drawn: 1st. That the efficiency of the regenerator increases nearly in proportion to the density of the air, but in a somewhat slower ratio; and it may be concluded that the efficiency of all other surfaces, such as the ends of the cylinder in the model refrigerator,

which give out or abstract heat from air, increases nearly as the density.

2ndly. For a difference of temperature of 150° between the hot and the cold sides of a regenerator, if, as in these experiments, the regenerator is clean and all the surface effective, it is not necessary to use more than fifty layers of gauze. This gives one layer of gauze for each 3° difference of temperature.

3rdly. Only the surface exposed to the action of the air in a regenerator is of value (within at least any limits possible in practice), the proportion of weight of material in a regenerator to weight of air passed through it being of no value.

The Author will now proceed to describe the machine which was actually made. Plate 10, Fig. 3 is partly a longitudinal section and partly an elevation. Fig. 4 is a transverse section of the cooling machine, the steam-engine which drives it being omitted. This needs no description, being simply an ordinary horizontal engine, placed in line with the horizontal cylinder A of the cooling machine, and having the piston-rod of the engine prolonged through the back cover of the cylinder, and coupled to the piston-rod B of the air machine. The steam-engine thus moves the piston, C, backwards and forwards. The crank shaft of the engine carries an eccentric, placed at right angles to the crank, which by an eccentric rod taking on to the pin D, in the lever E, by the intervention of the lever F and the rods G, moves the pistons L, containing the regenerators H, up and down in the cylinders I. The cylinder A corresponds to the compressing pump of the model, and the cylinders I I to the cooling cylinder of tin in the model. In this case, as the cylinder A is double acting, each end is furnished with a cooling cylinder and displacing piston. The cylinder A, of hard close iron, has a table cast on it, on which the cooling cylinders I I stand, and to which they are bolted down by long bolts passing through the cover, and grasping together the cylinder and plates which form the water passages. At the ends of the cylinder A, a port opens into the centre of each of the cooling cylinders I, through which also the piston rods K work in air-tight stuffing boxes; the whole, with the covers on the cylinders, forming a pair of compound air-tight vessels, whose capacity is varied as the piston C moves backwards and forwards, and thus the air contained in each is alternately compressed and expanded. The cylinder I is divided into two compartments by the piston L, through which the air can pass by a number of small holes in the top and bottom plates, so that when the piston is moved upwards the air will be shifted from the

upper compartment to the lower, and *vice versâ*. Inside this piston is the regenerator H, in a light brass square box, occupying as much of the area of the piston as possible, the segmental spaces left being filled with Portland cement. One side of each of these compartments (the top and bottom of the cylinder) is a corrugated plate of cast iron, M M, one side of which is fitted pretty nearly by the piston, while on the other side the grooves between the plate and the supporting covers afford a series of channels through which, on the top side, brine is caused to flow, entering by the pipe N, and escaping by the pipe O, passing in succession through both cylinders; while on the under side water of the ordinary temperature enters by the pipes P and P, and escapes by the pipes Q and Q. The corrugations are in concentric circles, the water flowing round one groove, passing into the next, flowing round that one, and so on. Fig. 5 represents a section of one of these grooves, R. The space S, cut through the thick metal left at the apex, allows the water to pass from one groove to the other, a stopper being fixed in the groove close to the gap to divert the water into the next channel. Small air-pipes, T, one in each bottom groove, ensure the water filling them to the top. The thick metal at the apex of the grooves forms also a means of dovetailing in steel bolts, which, passing through the covers, prevent the plates from being sucked in and thus broken, when, as on first starting, the machine is not sufficiently charged with air.

By these arrangements not only is a large surface exposed in the corrugated plates, but what is of equal importance, in order that the air may absorb heat or give it out to the surface so exposed, the ridges on the piston, combined with the rushing of the air through the numerous small holes, as the piston L moves up and down, causes a rapid circulation of air over the plates, and, as far as possible, brings every particle in contact with them. Still this intimate contact of every particle of air with the metallic surface is much less perfectly accomplished than by the more finely-divided surface of the regenerator; and there is reason to believe, though the Author has not measured it, that, in the one case, the temperature of the air is considerably below that of the brine, and in the other considerably above that of the cooling water.

The action is precisely similar to that already described in the model. The piston C compresses the air in contact with the lower corrugated plate, to which it parts with the heat generated during compression. The piston L moves down, causing the compressed air to pass through the regenerator to the space between the piston and the upper corrugated plate. The piston C then moves back,

under the action of the expanding air, which, in so doing, extracts heat from the upper corrugated plate.

This action is shown in Plate 10, Fig. 6, in which the circumference of the path of the crank is laid off in equal parts on the horizontal line A B C, A B representing one complete revolution. The clearances, space for the regenerator, and space traversed by the piston of the cooling cylinder, are reduced to, and represented by, the corresponding lengths of the compressing cylinder. These spaces are set off on the vertical ordinates corresponding to the position of the piston. Thus the ordinates of the curve below the line D E represent the distance of the compressing piston from the end of the cylinder; those from D to F represent the clearance between the compressing piston and the regenerator; from F to G the working air below the regenerator; from G to H the air in the regenerator, the motion of which is shown by curved lines; from H to I the working air above the regenerator, and lastly, those from I to K, the clearance on the top of the regenerator. The spaces occupied by the air in the various positions of the several parts of the machine are thus clearly shown. From this it will be seen that the operations are not performed by sudden transitions, and that a little compression is performed at the cold end, and a little expansion at the hot end. A greater weight of air is compressed than is expanded, part of the cushion of air entering the space under the regenerator during compression and being cooled. This, on being shifted to the cold end, escapes through the regenerator, gradually, as expansion goes on, leaving in the regenerator what cold it has generated during this partial expansion. As the driving stress is variable a heavy fly-wheel is required, whether the motive power be steam or water. The ends of the compressing cylinder are connected by a pipe containing a valve, by opening which the air can pass freely from one end of the cylinder to the other. By the help of this pipe the machine can be started easily, and when the fly-wheel has acquired sufficient momentum the valve is shut.

The air contained in the machine may be at any pressure which the machine can withstand. The machines are usually worked at from 100 lbs. to 120 lbs. per square inch maximum pressure, the efficiency and capacity of the machine for work increasing with increased pressure. To keep up this pressure, a small compressing pump draws air through a couple of boxes containing chloride of calcium, two being used that they may be filled alternately with freshly fused chloride, and the air be drawn first through the one which has been longest in use, and next through the one freshly

filled. This is necessary to dry the air; for if the air be damp the moisture is deposited as snow in the upper parts of the regenerator, and by obstructing the air passages may do mischief. As in spite of all precautions a little moisture will get in, the following arrangement has been added to most of the machines, to avoid the necessity of removing the regenerator, and drying it at the fire. The eccentric rod is provided with an arrangement by which it can be disconnected from the driving pin in the lever E, Fig. 4, and thus all cooling action, although the compressing piston continues to work, will be stopped. By opening a valve, making a communication between the upper or cold ends and the open air, and working the compressing piston, the air by its friction in rushing through soon warms the regenerator, and evaporates the moisture from the interior. Originally these valves were connected by a pipe, so that, on working, the air passed from one cooling cylinder to the other, traversing in its way a box containing chloride of calcium. This formed a much more powerful drying apparatus, as the temperature inside was quickly raised to a higher degree. But as attendants are often careless, and allow the chloride in the box to become damp, fine dust is thus blown over, which clogs up the air passages; and this has led, in some cases, to its being disused.

Besides enabling the use of all dangerous fluids to be dispensed with, which was the principal object in adopting this machine at the Bathgate Works, experience there established its great superiority, as so few repairs were required, due chiefly to the absence of valves, and to the use of common cupped leather packings. The repairs were of about the same amount and kind as for an ordinary steam-engine, and could be made without deranging the regular operations of the works, and by an ordinary mechanic. The cooling cylinder requires no lubrication, except being smeared with oil before putting in the piston, and very little oil is sufficient for the compressing cylinder—less than a gill in twenty-four hours.

The present original Bathgate machine (the first having been destroyed in a fire which consumed a large part of the works) was started in the year 1864, and has since worked continuously night and day (Sundays excepted), being only stopped for a day or two once in six or eight months, and thoroughly cleaned inside.

The Author will now proceed to describe a modification of this machine, lately introduced, more especially to meet the case, for which the machine in the form just described is not well adapted, when it is required to cool large quantities of water, as in breweries,

or for ice making, or for any other purpose when a temperature is not required below 22°. This machine differs from the other chiefly in the corrugated plates being dispensed with, and the water or brine to be cooled, and the water to remove the heat of compression being injected amongst the working air. The interior of the machine requires no oil for lubrication, and the air is not required to be kept dry. To meet these conditions in a simple manner the arrangement of the machine was modified, the action of the air being the same as in the former machine. The machine consists essentially of two cylinders, A and B (Plate 11, Figs. 7, 8, 9), each containing a double-acting plunger, and each connected to a crank fixed on a revolving shaft at any angle between 180° and a right angle, though the Author prefers to place them from 135° to 120° apart. These cylinders are connected at each end by large open passages, C, C, which contain each a regenerator, and through which, on the plungers being moved, the air can pass freely from one cylinder to the other.

The water to be cooled is allowed to flow down in front of one end of the regenerator at D, while the water used to remove the heat of compression is allowed to flow down the face E of the other end of the regenerator. The water thus flowing constantly into the machine escapes through valves, whose opening is governed by a float F. One cylinder is in this arrangement cold at both ends, absorbing heat, and the other hot at both ends, rejecting heat, an arrangement favourable to reducing conduction from the hot to the cold parts of the machine.

To make the action of the two plungers more clear, the Author has prepared a diagram, Fig. 10, on the same principle as the one already described for the dry-air machine, the clearances and spaces for the regenerator being represented on the vertical ordinates by the lengths of cylinder equal to them respectively, while the horizontal divisions represent equal parts of the circumference traversed by the crank pin. A B represents the circumference traversed by the crank of the hot cylinder, C D the circumference traversed by the crank of the cold cylinder, in their respective positions in regard to each other. A E and H K are the strokes of the plungers in the hot and the cold cylinders respectively. E F is the clearance between the hot plunger and the regenerator. F G is the regenerator. G H is the clearance between the regenerator and the cold plunger.

The ordinates from one curve to the other, such as E I, at each point of the circumference, represent the space occupied by the air at that position of the plungers, and the parts of these

lines below and above the regenerator represent respectively the space occupied by the hot air and the space occupied by the cold air. On examining these ordinates and the curves it will be seen that there are regular points of greatest compression and greatest expansion, as at L L and Q Q, and that on either side of these from M M and N N, and from O O to P P, the curves run nearly parallel. From M M to N N the air is being shifted with little change of volume from the hot cylinder to the cold; then, the hot plunger remaining nearly stationary, the cold plunger moves rapidly, causing expansion; from O O to P P the curves again run nearly parallel, shifting the air with little change of volume from the cold cylinder to the hot; and, finally, completing the revolution, the cold plunger remains nearly stationary, while the hot plunger moves rapidly and compresses the air.

These operations, it will be seen, are not performed by sudden transitions, and a little compression takes place in the cold cylinder, and a little expansion in the hot. A comparison of this diagram with Fig. 6 will show the much larger size of regenerator found necessary when using moist air compared with what was required when using dry air. The cushion of air in the clearances is less, which is an advantage. The compressions and expansions, which the air in the regenerator undergoes, so nearly neutralise each other that except in minute calculations they may be left out of account.

In all essential respects the action of the air in this arrangement is precisely similar to that already described in the dry-air machine. The general arrangement of the only machine of the kind yet regularly at work will be seen on referring again to Figs. 7, 8, 9. The two air cylinders, A and B, containing the plungers, are each connected by a distance-piece to two steam cylinders, one larger than the other, and intended to be worked as a compound engine, a horizontal condenser and air pump being placed between, but omitted in the drawing for the sake of clearness. The steam cylinders also have connections enabling the engine to be worked non-condensing. The other parts of the engine need no description. F, G, H, and I, Fig. 8, are four water-pumps, worked by a rocking shaft. The pump F draws the water to be cooled from a cistern, and forces it into the cylinder at K, where it flows down a screen composed of a few sheets of coarse wire gauze placed in front of the regenerator W, and escapes out through the valve L, Fig. 8, which is regulated by a float F, Fig. 9. The pump G then takes this water as it escapes from the valve, and forces it into the opposite end of the same cylinder at

L 2, when it flows down a similar arrangement in front of the regenerator, and escapes through a regulating valve and float at M. Similarly the pump H draws the water used to carry off the heat of compression, forces it into the cylinder at N, escaping at O through a valve. From this it is taken by the pump I, and forced into the opposite end of the cylinder at P, escaping through a valve at Q. The internal arrangements of gauze, floats, and valves, are in every way the same as for the cold cylinder. By admitting the water to be cooled, and the water used to remove the heat of compression at opposite ends of their respective cylinders, the water in its second stage of cooling, when its temperature is most reduced, has its heat removed by the cooling water in its first stage of being warmed, when its temperature also is lowest; and the water, when it enters or is in its first stage of cooling, has its heat removed by water in its second stage of being warmed. By this arrangement, the difference of temperature between the hot and the cold ends of the regenerators is nearly the same.

Worked by the same shaft as the water pumps, an air compressing pump R maintains the required pressure of air, drawing its supply from the atmosphere direct, without, as in the other machine, passing through a drying medium. Two small pumps, S and T, maintain a pressure of water in the belts, U and U, which encircle the cylinders and keep the leathers up to the plungers against the pressure of the air. At the same time the water-belt serves to keep the leathers thoroughly wet and lubricated. The reason of there being two such pumps is, that the machine is worked generally at a temperature of 25° to 27°, and brine is used in the cold cylinder and its belt, while fresh water is used in the warm cylinder and its belt. If the lowest temperature required had been about 40°, fresh water could have been worked in both cylinders, and the double pumps dispensed with.

This machine was started at the works of the Oakbank Oil Company in June 1872, and since that time has been continuously at work. Being the first machine of the kind, it is capable of much improvement. The regenerators, the Author ascertained during an elaborate series of experiments on a small scale, required to be very different from those used in the dry-air machine. Gauze which answered so well with dry air was ineffectual with moist air, as the water adhered so strongly to the meshes as to prevent the air from being forced through. The regenerator, also, had to be made larger. A regenerator composed of plates was found

to be the best; but at the time, it was almost impossible to get such plates made on the scale required. In consequence, the Author had to use the thinnest sheet brass he could get, though much thicker than was desirable, with rows of holes punched 2 inches apart, to prevent, as much as possible, conduction of heat from the hot to the cold edge of the sheet. The arrangement was by no means perfect, but the Author had to be content, as it was the best that could be had at the time.

The mechanical friction, too, is great in this machine, higher than in the arrangement of the dry-air machine with three cylinders, since the shifting of the air from one cylinder to the other is accompanied with nearly as much mechanical friction as the compression and expansion. By a re-arrangement of the working parts, the Author will be able in future to remedy this defect, while retaining the two cylinder arrangement, which has the advantage of simplicity, and greater freedom from loss by conduction of heat from the hot end to the cold than by the other plan, where one end of the same cylinder is hot while the other end is cold. These imperfections have not affected the successful working of the machine, which has done its work continuously and without trouble, but they cause an increasing consumption of power. In the Oakbank works this is a point of incomparably less importance than the machine doing its work regularly with little trouble to any one, and with perfect safety even in careless hands.

The two arrangements of refrigerating machines described, which may be called the dry-air and the wet-air machines, have each a value of their own, and are suited to different purposes. With the dry-air machine the most intense degree of cold may be produced; with the wet-air machine, so far as the Author's experience has yet gone, the range is limited to 22° Fahrenheit for continuous working, but within that range is to be preferred.

By the specially constructed model already described the Author froze mercury, and in so doing maintained a difference of temperature in the apparatus of almost 100°. Had two such machines been employed, the first cooling spirit to, say, 100° below the temperature of the atmosphere, and had this spirit been employed, circulating in a continuous current, to abstract the heat of compression from the air in a second similar machine, so far as internal conduction is concerned, a difference of temperature of 100° might again be got, equivalent to a total cooling of 200°. It is not to be expected that quite the same difference of temperature could be

maintained in the second machine as in the first; for although internal conduction would be no greater, the tendency to loss of cold by external conduction would be greater, and more difficult to prevent. Still the Author has no doubt that, by dividing the operation of cooling into two or more steps, degrees of cold can be reached and maintained that have not hitherto been attainable, and that this machine may yet prove an important instrument in physical research.

The wet-air machine is more limited in the range of temperature through which it is applicable, but within that range it is more convenient and economical. Without involving the construction of enormous cooling surfaces, and maintaining these air-tight, the temperatures of the air and water are nearly equalised, which it is all but impossible to do with dry air. Lubrication of the interior is not required, nor is it necessary to keep the working air dry. Simple as the last point may seem, the Author has had more trouble from the neglect of this precaution than from every other thing connected with the dry-air machine. A new attendant could not be got to believe that chloride of calcium might be filled with water and yet appear dry; and though all that had to be done was to fuse the chloride which had become filled with moisture in an iron pot, and replace it in the boxes provided for it, this was seldom properly done till after a time of unsatisfactory work had shown the necessity for attending to these instructions.

Probably cooling air by expansion, and subjecting the moisture contained in it to intense cold, will be found a more efficient method of drying air than passing it through either chloride of calcium or sulphuric acid. By no extent of chloride of calcium (and the small quantity of air to supply leakage has been passed through a column 10 feet long by 6 inches in diameter) has the Author succeeded in completely preventing a deposit of snow.

In conclusion, the Author will give a few examples of the working of these machines. If these are not so numerous, or, in the case of the dry-air machine, so recent as could be wished, he hopes forbearance will be shown, as it is with much difficulty that complete results can be got from machines working daily, and forming a component part of other extensive manufacturing operations.

The only really complete trials of the dry-air machine were those made in 1864 by the Author, while manager of the Bathgate works, of which the following is an average sample:—

Dry-air Machine.

Diameter of cooling cylinders[1]	36 inches.
Stroke	$2\frac{3}{4}$ „
Diameter of compressing cylinder	15 „
Stroke	30 „
Pressure of air in one cylinder, by gauge	100 lbs. max. 46 „ min.
Ditto „ other „ „	110 „ max. 52 „ min.
Revolutions per minute	66
I.H.P. spent in driving, including friction	23
Quantity of cooling water per minute	4.3 gallons.
Temperature of inflow	62°
Ditto outflow	94°
Quantity of brine cooled per minute	6·7 gallons.
Temperature of inflow	32°
Ditto outflow	23°·5

Wet-air Machine.

The average of five hours' trial at the maker's works before the machine was erected at Oakbank—June 24, 1871—gave,—

Diameter of hot and cold cylinders	36 inches.
Stroke	36 „
Diameter of barrel (plunger and bucket) of hot and cold water pumps	6 „
Stroke	6 „
Revolutions per minute	35
HP. (by diagrams from steam engine) spent in driving, including friction	37
Ditto, by diagrams from air cylinder	26·3
Quantity of cooling water per minute	20·3 gallons.
Temperature of inflow	63°·25
Ditto outflow	81°
Quantity of fresh water cooled per minute	20·6 gallons.
Temperature of inflow	61°·25
Ditto outflow	47°·25

The trial of the same machine when at work, cooling paraffin oil, at the Oakbank works, Midcalder—Dec. 14, 1872—gave,—

Revolutions per minute	34
HP. (from diagrams of steam cylinders) spent in driving, including friction	25
Quantity of cooling water per minute	18·55 gallons.
Temperature of inflow	67°
Ditto outflow	73°
Quantity of brine cooled per minute	13·05 gallons.
Temperature of inflow	37°
Ditto outflow	28°·25

[1] *Vide* Transactions of the Institution of Engineers in Scotland, vol. viii., p. 20.

Owing to the condition of the work which the machine was doing, it was unfortunately necessary to reduce the flow of brine to nearly one half of what it ought to have been. As in this state the screens were imperfectly washed by the brine, and the air imperfectly warmed, the efficiency of the machine was somewhat reduced.

These results, the Author is well aware, leave much room for improvement. To ascertain what the ultimate limit of perfection is in the two classes of machines, the Author has assumed temperatures for the air at the hot and cold ends of the machines corresponding probably to what may have been the case in the above experiments, and has calculated the power required, and the amount of absorbed and rejected heat, for a machine of each kind containing 1 lb. of air. The method he adopted was to set out curves *k k* and *d d*, and *k k* and *e e* on the diagrams, Fig. 6 and Fig. 10, of the dry and the wet-air machines respectively, whose ordinates show the bulk of the air in the cold and hot compartments at each corresponding part of the revolution, on the supposition that the air of the cold compartment is heated, and the air in the hot compartment is cooled, to the temperature of the regenerator, which is assumed to be a mean between the temperatures of the hot and cold compartments. These ordinates give the actual expansion of the air; and the ratio of one ordinate to the next gives the ratio of expansion, while the ratios of the three parts of which each ordinate is composed—the part in the hot chamber, the part in the regenerator, and the part in the cold chamber—give the ratios in which the work of compression or expansion in passing from one ordinate to the next is to be divided, in order to find how much is performed in the hot chamber, in the regenerator, and in the cold chamber.

Calculating thus the thermo-dynamic functions ($122{\cdot}38 \times$ log. ratio of expansion) for each ordinate, and dividing it into three parts in proportion to the parts into which this ordinate is divided, and adding, there is obtained the function for the compression of the air in each of the three compartments, and also for the expansion. Multiplying by the absolute temperature, the result is the foot lbs. of power in each.

Calculated thus, the results for 1 lb. of air are—

1. In the dry-air machine, Fig. 6: temperature of rejecting heat, 587°; temperature of regenerator, 524°; and temperature of absorbing heat, 461°, absolute.

Work spent in Compression.

	In hot chamber.	In regenerator.	In cold chamber.
Foot lbs.	14066·281	1332·532	2610·643

Work performed by Expansion.

	In hot chamber.	In regenerator.	In cold chamber.
Foot lbs.	8623·617	1223·540	6982·306

Total foot lbs. spent in compression . . .	18009·456
„ „ performed by expansion. . .	16829·463
Foot lbs. required to drive machine . . .	1179·993

The rejected heat expressed in foot lbs. is the difference between the work of compression and of expansion in the hot chamber; and the absorbed heat is, similarly, the difference between the work of expansion and of compression in the cold chamber, as some heat is generated in the regenerator = 1332·532 − 1223·540 = 108·992, half of this may be added to the rejected heat, and half deducted from the absorbed heat. Thus—

$$\text{Rejected heat} = \frac{14066{\cdot}281 - 8623{\cdot}617 + 54{\cdot}496}{772}$$

$$= 7{\cdot}12 \text{ lbs. of water heated } 1^\circ \text{ F.}$$

$$\text{Absorbed heat} = \frac{6982{\cdot}306 - 2610{\cdot}643 - 54{\cdot}496}{772}$$

$$= 5{\cdot}59 \text{ lbs. of water cooled } 1^\circ \text{ F.}$$

2. In the wet-air machine, Fig. 10: temperature of rejecting heat 561° absolute; temperature of absorbing heat 476°; temperature of regenerator 518°.

Work spent in Compression.

	In hot chamber.	In regenerator.	In cold chamber.
Foot lbs.	7083·747	2883·706	2494·240

Work performed by Expansion.

	In hot chamber.	In regenerator.	In cold chamber.
Foot lbs.	2005·014	3045·840	6654·480

Total foot lbs. spent in compression . . . . . 12461·693
Total foot lbs. performed by expansion . . . . . 11705·334

Foot lbs. required to drive machine . . . . . 756·359

Heat generated in regenerator = 3045·840 − 2883·706 = 162·134

$$\text{Rejected heat} = \frac{7083{\cdot}747 - 2005{\cdot}014 + 81{\cdot}067}{772}$$

= 6·68 lbs. of water heated 1° F.

$$\text{Absorbed heat} = \frac{6654{\cdot}480 - 2494{\cdot}240 - 81{\cdot}067}{772}$$

= 5·28 lbs. of water cooled 1° F.

The above results are for one revolution, or one complete operation of compression and expansion.

As the dry-air machine at Bathgate contained about 3 lbs. of air at the time the trial above given was made, the results, if perfect, and without loss by conduction or friction, would have been—

Indicated HP. 7·08
Rejected heat, 1,409 lbs. of water, 1° per minute.
Absorbed heat, 1,106 lbs. of water, 1° per minute.

As the wet-air machine in the second experiment contained about 10 lbs. of air, the perfect result would have been—

Indicated HP. 7·8
Rejected heat, 2271·2 lbs. of water, 1° per minute.
Absorbed heat, 1795·2 lbs. of water, 1° per minute.

In the calculation of the wet-air machine the Author has taken it as if the air were dry, and not saturated with moisture, as the calculation for saturated air presented difficulties beyond his power.

The Paper is accompanied by a series of drawings and diagrams, from which Plates 10 and 11 have been compiled.

DRY AIR MACHINE.

Fig. 1.

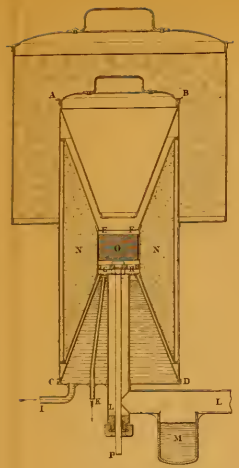


Fig. 2.

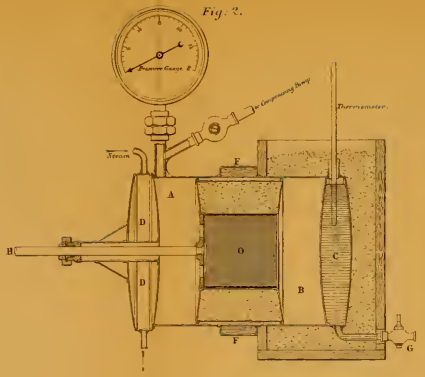
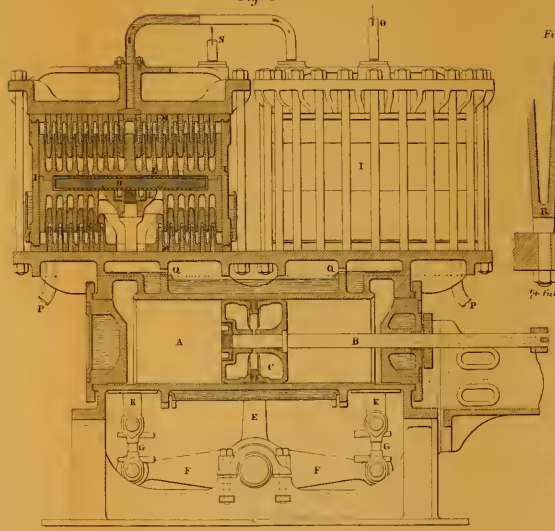


Fig. 3.



SECTIONAL ELEVATION.

Fig. 5.

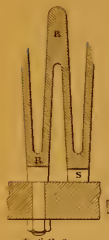
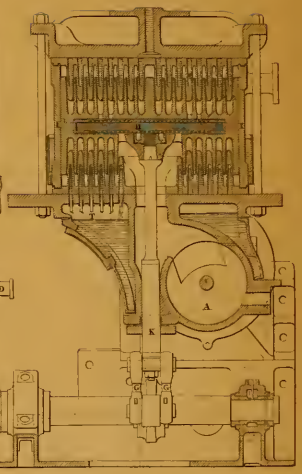


Fig. 4.



CROSS SECTIONAL ELEVATION.

Fig. 6.

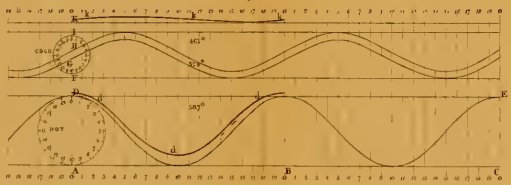


Fig: 7.

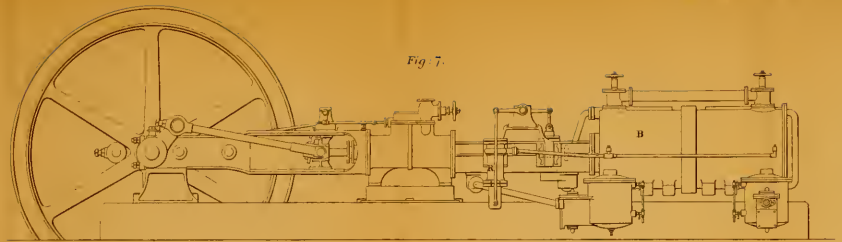


Fig: 8.

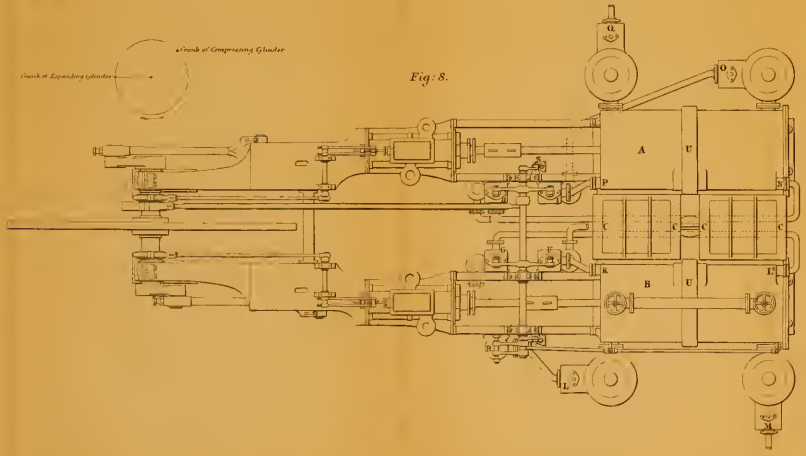


Fig: 9.

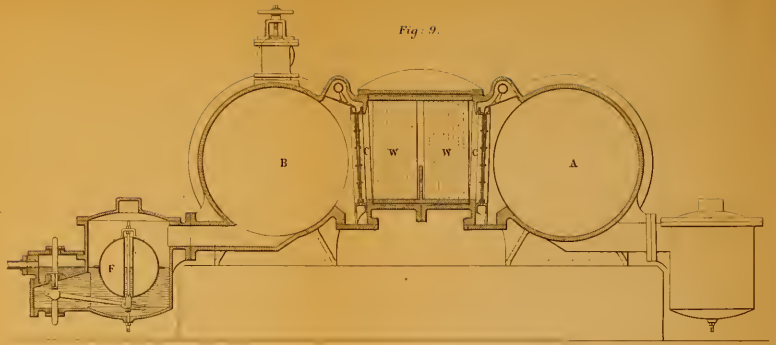
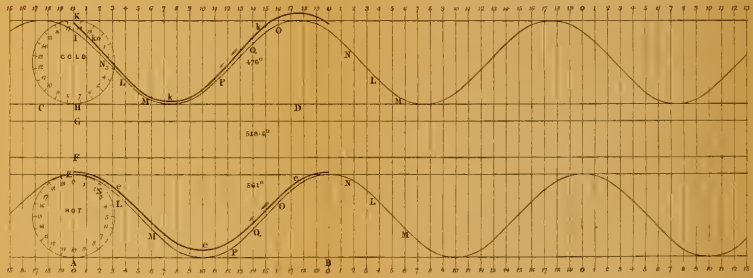


Fig: 10.



APPENDIX.

CONTRIBUTION TO THE BIBLIOGRAPHY OF MECHANICAL REFRIGERATION.[1]

This list is restricted to contrivances for mechanical refrigeration and the manufacture of ice by the expansion of compressed air and the artificial vaporisation of liquids, and does not comprehend processes in which refrigeration is produced by spontaneous evaporation or radiation, or by the agency of freezing mixtures.

An examination of the official lists of patents granted in Great Britain, France, and the United States, brought to light such a large number of patents on this subject, that the recapitulation of them has been omitted, as the list would else have been too voluminous to be convenient. Some of these patents are noticed, however, as having been described in contemporary publications.

ABBREVIATIONS.

Am. Art. American Artisan.
Ann. G. civ. Annales du Génie civil.
Ann. Land. Annalen der Landwirthschaft. Wochenblatt.
Bay. Bierbr. Bayerische Bierbrauer.
Bay. I.- u. G.-Bl. Bayerisches Industrie- und Gewerbe-Blatt.
Bull. S. d'Enc. Bulletin de la Société d'Encouragement.
Ch. C.-Bl. Chemisches Centralblatt.
Col. Column.
Compt. r. Comptes-rendus de l'Académie des Sciences.
Cop. Copied.
Deut. Gew. Wieck's Deutsche Gewerbezeitung.
Deut. Ind.-Z. Deutsche Industrie-Zeitung.
Ed. Edition.
Eng. Engineer.
Engng. Engineering.
Gew. Württ. Gewerbeblatt aus Württemberg.
Gén. ind. Armengaud's Génie industriel.
J. Fr. Inst. Journal of the Franklin Institute.
J. Soc. Arts. Journal of the Society of Arts.
K.- u. Gew.-Bl. Kunst- und Gewerbe-Blatt.
Lond. J. Newton's London Journal of Arts and Sciences.
Mech. M. Mechanics' Magazine.
Mém. S. Ing. c. Mémoires et Compte-rendu des travaux de la Société des Ingénieurs civils.
Mon. sc. Quesneville's Moniteur scientifique.

[1] This contribution has been furnished by Mr. John Bourne. Sec. Inst. C.E.

P. Page.
Pl. Plate.
Pol. C. Polytechnisches Centralblatt.
Pol. J. Dingler's Polytechnisches Journal.
Port. éc. Oppermann's Portefeuille économique des Machines.
Pr. Masch.-C. Practische Maschinen-Constructeur.
Pr. Mech. J. Practical Mechanic's Journal.
Pr. R. Soc. Ed. Proceedings of the Royal Society of Edinburgh.
Publ. ind. Armengaud's Publication industrielle des Machines.
Rép. Ch. ap. Répertoire de Chimie appliquée.
S. Series.
Sc. Am. Scientific American.
Tech. Technologiste.
Trans. Translated.
V. Volume.
Zeit. V. d. Ing. Zeitschrift des Vereines deutscher Ingenieure.

Date of Publication.	Titles.	Inventions chiefly referred to.
1663 ("Century of Inventions").	Ffountaines of pleasure, with artificiall snow or haill or thunder, and quantity not limitted.—Dircks' Life and Times of the Marquis of Worcester, 1865, pp. 316 and 412–14.	Marquis of Worcester's.
1781	An account of some thermometrical experiments; containing, I. Experiments relating to the cold produced by the evaporation of various fluids, with a method of purifying ether. By Tiberius Cavallo, F.R.S.—Philosophical Transactions, v. 71, 1781, pp. 509–20.	——
1813	Experiments on the production of cold by the evaporation of the sulphuret of carbon. By Alex. Marcet, M.D., F.R.S.—*Ibid.*, v. 103, 1813, pp. 252–55.	——
1824	Prof. Leslie's process for making ice.—Mech. M., v. 1, 1824, pp. 311–14 and 322–23.	Leslie's.
1824	Patent granted to John Vallance, of Brighton, Esq., for his invention of an improved method of freezing water.—Lond. J., v. 8, 1824, pp. 251–53 and pl. XI.—Trans. in Bulletin des Sciences technologiques, v. 3, 1825, pp. 44–45 and pl. I.—Also in Pol. J., v. 16, 1825, pp. 227–29 and pl. IV.	Vallance's.
1826	Phenomenon attending the working of the Hungarian pressure engine erected at Chemnitz in 1755.—Gregory's Treatise of Mechanics, 4th ed., v. 2, 1826, p. 226.—Also in Library of Useful Knowledge. Natural Philosophy, v.. 1, 1829, Hydraulics, p. 19.—Ewbank's Hydraulic and other Machines for Raising Water, 1842, p. 362.—Dircks' Life and Times of the Marquis of Worcester, 1865, p. 414.	——
1826	Patent granted to John Vallance, of Brighton, Esq., for his invention of an improved method or methods of abstracting or carrying off the caloric of fluidity from any congealing water, (or it may be other liquors;) also, an improved method or	Vallance's.

Date of Publication.	Titles.	Inventions chiefly referred to.
	methods of producing intense cold; also, an improved method or methods of applying this invention, so as to make it available to purposes, with reference to which temperature above or below the freezing point may be rendered productive of advantageous effects, whether medical, chemical, or mechanical.—Lond. J., v. 11, 1826, pp. 298–302 and pl. XV.—Trans. in Pol. J., v. 21, 1826, pp. 412–15 and pl. VIII.	
1828	Artificial cold. Letter by Trevithick in 1828. —Fr. Trevithick's Life of Richard Trevithick, v. 2, 1872, pp. 294–95.	Trevithick's.
1849	Ice made by mechanical power.—Sc. Am., v. 5, 1849, p. 3.	Gorrie's.
1849	On Gorrie's invention.—Athenæum, 1849, pp. 1277–78.	Gorrie's.
1850	Making ice. Letters from Sir J. F. W. Herschel and Ch. May.—*Ibid.*, 1850, pp. 22–23.	Herschel's.
1850	On a method of cooling the air of rooms in tropical climates. By Prof. Piazzi Smyth, Astronomer Royal for Scotland.—Pr. Mech. J., v. 3, 1850, pp. 155–57 and 194–98.	Smyth's.
1850	Appareil à produire de la glace par Gorrie.—Moniteur industriel, 1850, p. 1413.—Trans. in Pol. J., v. 115, 1850, pp. 159–60.	Gorrie's.
1851	On a method of cooling the atmosphere of rooms in a tropical climate. By Prof. C. Piazzi Smyth. —Pr. R. Soc. Ed., v. 2, 1851, pp. 235–36.	Smyth's.
1851	Experiments on the thermotic effect of the compression and expansion of air. By Prof. Piazzi Smyth.—Edinburgh New Philosophical Journal, v. 51, 1851, pp. 114–19.	Smyth's.
1851	On the relation between the changes of temperature and volume of gases. By Wm. Petrie, Esq., C.E. —*Ibid.*, v. 51, 1851, pp. 120–25.	——
1851	On spontaneous re-heating of air cooled by issuing, in a jet, from a more compressed state. (An important fact, if correct, in regard to the practical application of such variations of temperature.) By Wm. Petrie, Esq., C.E.—*Ibid.*, v. 51, 1851, pp. 125–28.	——
1851	On the re-heating of jets of air, and the relation between temperature and compression of the same. By W. J. Macquorn Rankine, C.E.— *Ibid.*, v. 51, 1851, pp. 128–30.	Smyth's.
1851	Manufacture of ice. Dr. Gorrie's process.—Letter from Salud, near Havanna.—Mech. M., v. 54, 1851, pp. 87–89.	Gorrie's.
1852	Patent granted to Wm. Edw. Newton, of the Office for Patents, 66, Chancery Lane, for improvements in machinery or apparatus for producing ice, and for general refrigerating purposes, being a communication.—Lond. J., conjoined s., v. 39, 1852, pp. 137–48 and pl. II.	(A foreigner's.)
1852	Remarks on the mechanical process for cooling air in tropical climates proposed by Prof. C. Piazzi Smyth. By W. J. M. Rankine, C.E., F.R.S.E.—	Smyth's.

Date of Publication.	Titles.	Inventions chiefly referred to.
	Report of the British Association for 1852, 1853, Transactions of the Sections, pp. 128–29.	
1853	Cooling air by expansion.—Civil Engineer and Architect's Journal, 1853, pp. 364–65.—Trans. in Pol. J., v. 130, 1853, pp. 412–14 and pl. VI. (Abstract of report and memorial to the East India Company, by Mr. W. J. M. Rankine, read before the British Association in 1853, and not published in its Reports.)	Smyth's.
1853	Congélation.—Laboulaye's Dictionnaire des Arts et Manufactures, v. 1, 1853.	Taylor and Martineau's.
1854	Cold (by Prof. Leslie ?).—Encyclopædia Britannica, 8th ed., v. 7, 1854, pp. 99–108 and pl. clxxxvii.	Leslie's.
1854	Ice-making machinery.—J. Soc. Arts, v. 2, 1854, p. 250.	Gorrie's.
1857	Accouut of experiments on the thermotic effect of the compression of air, with some practical applications. By Prof. C. Piazzi Smyth.—Theoretical investigations into the same by W. Petrie, Esq.—Pr. R. Soc. Ed., v. 3, 1857, pp. 28–29.	Smyth's.
1857	Production économique de la glace par l'évaporation de l'éther dans le vide.—Journal de Pharmacie et de Chimie, 3rd s., v. 31, 1857, pp. 449–50.—Trans. in Pol. C., 1857, p. 1031.	Harrison's.
1857	Appareil de M. Harrison pour fabriquer la glace.—Cosmos, v. 11, 1857, pp. 201–3 and 289–91.—Trans. in Pol. C., 1857, pp. 1506–8 and pl. 44.	Harrison's.
1858	Eismaschine aus der Fabrik von James Watt.—Zeit. V. d. Ing., 1858, p. 287.	(?)
1859	Eis. — Eiskeller. — Künstliche Eisbildung und Abkühlung des Wassers.—Artmann's Lehre von den Nahrungsmitteln, 1859, Prague, pp. 177–84.—Cop. in Deut. Gew., 1859, pp. 383–85.—Also in K.-u. Gew.-Bl., 1860, pp. 163–72.	Various.
1860	Fabrication de la glace. — Indépendance Belge, Jan. 3, 1860, Supplément. — Trans. in Gew. Württ., 1860, p. 264.—Cop. in Pol. C., 1860, p. 1343.	Carré's.[1]
1860	Künstliche Eiserzeugung. — Breslauer Gewerbe-Blatt, 1860, pp. 5–6.—Cop. in Deut. Gew., 1860, p. 157.	Various.
1860	Rapport fait, par M. Ch. Laboulaye, au nom du comité des arts mécaniques, sur un appareil destiné à la production artificielle de la glace inventé par M. Carré, rue Saint-Louis-en-l'Ile, 75.—Bull. S. d'Enc., 1860, pp. 129–40 and pl. 190.—Cop. in Laboulaye's Dictionnaire des Arts et Manufactures, v. 3, Complément, 1861, pp. 489–92.—Trans. in Pol. J., v. 158, 1860, pp. 109–15 and pl. II.—Also in Bolley's Handbuch der chemischen Technologie, v. 1, 1st group: Die chemische Technologie des Wassers, 1862, pp. 121–27.	Carré's.

[1] There are two Carrés, who are brothers, and each is connected with a different ice-making machine.

Date of Publication.	Titles.	Inventions chiefly referred to.
1860	Production artificielle de la glace.—Appareil à vapeur d'éther de M. Carré. Par A. Brüll, ing. civ.—Port. éc., 1860, col. 84–88.	Carré's.
1860	Beschreibung einer Fabrik zur Erzeugung künstlichen Eises in Liverpool; von Dr. Dullo in Königsberg i. Pr. — Pol. J., v. 158, 1860, pp. 115–17.—Cop. in Pol. C., 1861, pp. 209–11.—Cop. in Ch. C.-Bl., 1860, pp. 909–11.	(?)
1860	Note sur un appareil propre à produire le froid; par M. Carré.—Compt. r., v. 51,1860, pp. 1023–27.—Cop. in Bull. S. d'Enc., 1861, pp. 42–45.—Trans. in Pol. J., v. 160, 1861, pp. 23–27.—Also in Pol. C., 1861, pp. 1063–67.	Carré's.
1860	Procuring ice in India by mechanical means. By J. S. (Sked)—Eng. v. 10, 1860, p. 387.	——
1860	Eisbereitung. — Wagner's Jahres - Bericht der chemischen Technologie, 1860, pp. 457–58.	Various.
1861	Eiserzeugung.—*Ibid.*, 1861, pp. 501–3.	Various.
1861	Manufacturing ice.—Sc. Am., new s., v. 5, 1861, p. 72.	Harrison's.
1861	Appareil à produire le froid, par M. Carré.—Rép. Ch. ap., 1861, pp. 73–75.	Carré's.
1861	Refroidissement d'un gaz par sa dilatation.—Congélation de l'eau.—Péclet's Traité de la Chaleur, 3rd ed., v. 3, 1861, pp. 10–15.	Various.
1861	Manufacture of ice.—Pr. Mech. J., 2nd s., v. 6, 1861, p. 8.	Rizet's.
1861	Appareil pour produire de la glace par la liquéfaction de l'ammoniaque; réclamation de priorité adressée à l'occasion d'une communication récente de M. Carré; par MM. Ch. Tellier, Budin et Haussmann père. — Compt. r., v. 52, 1861, pp. 142–43. — Cop. in Rép. Ch. ap., 1861, pp. 103–4.—Trans. in Pol. C., 1861, p. 1163.—Also in Pol. J., v. 160, 1861, pp. 120–21.	Tellier's.
1861	Production du froid par l'absorption et la liquéfaction alternatives de gaz ou vapeurs et particulièrement du gaz ammoniac. Protestation de M. Carré.—Compt. r., v. 52, 1861, p. 208.	Carré's.
1861	Harrison's ice-making machine.—Eng., v. 11, 1861, p. 231.	Harrison's.
1861	Apparatus for making ice. (Invented by Carré and Co., Paris, France.)—Sc. Am., new s., v. 5, 1861, p. 256.—Cop. in Mech. M., new s.,v. 6, 1861, p. 310.	Carré's.
1861	Appareil propre à produire le froid. Par M. Carré.—Tech., v. 22, 1861, pp. 325–27.	Carré's.
1861	Refrigération et congélation artificielles. Par M. Rizet.—Tech., v. 22, 1861, pp. 329–30.	Rizet's.
1861	Cristallisation de divers sels et extraction du sulfate de soude par le froid artificiel. Par M. Carré, ingénieur chimiste à Paris.—Publ. ind., v. 13, 1861, pp. 386–94 and pl. 27.	Carré's.
1861	Fabrication continue de la glace par la circulation indéfinie de l'ammoniaque, tour à tour liquide et gazeux; appareil de M. Carré. Par F. Moigno.—Cosmos, v. 19, 1861, pp. 233–34.—Trans. in Pol. J., v. 163, 1862, pp. 180–84.	Carré's.

Date of Publication.	Titles.	Inventions chiefly referred to.
1861	Official reports to the Indian Government in regard to the establishment of ice-making machines at military stations.—Calcutta Government Gazette, June 22, 1861.	Siebe's.
1861	Apparat für künstliche Eiserzeugung von Carré & Comp. in Paris,—Gew. Württ., 1861, pp. 392–94.—Cop. in Verhandlungen und Mittheilungen des nieder-österreichischen Gewerbe-Vereines, 1861, pp. 163–65.—Also in Pol. C., 1861, pp. 1575–76 and pl. 45.—Also in Pol. J., v. 163, 1862, pp. 180–84.	Carré's.
1861	Production de la glace par l'acide sulfureux.—Tech., v. 22, 1861. p. 536.	Tellier's.
1862	Lawrence, H. M., & Co., Sandon Works, Sefton Street, Liverpool.—Machine for making ice by steam.—Official Illustrated Catalogue of the International Exhibition of 1862 v. 1, (1862), Class VIII, p. 40. (Lawrence, maker.)	(?)
1862	Siebe, Daniel, 17 Mason Street, Lambeth.—Harrison's patent ice-making machine.—*Ibid.*, v. 1, (1862), Class VIII, p. 67.	Harrison's.
1862	Cooling Apparatus Co. Carré & Co. 149 rue de Ménilmontant (Paris).—Machine for making ice by successive evaporations and liquefactions.—*Ibid.*, v. 3, Foreign Division (1862), p. 90.	Carré's.
1862	Production artificielle de la glace.—Rép. Ch. ap., 1862, pp. 292–93.	Various.
1862	Production du sulfate et du carbonate de soude par le froid, Machine Carré.—Exposition universelle de Londres de 1862.—Rapports des Membres de la Section française du Jury international, Introduction par M. Michel Chevalier, v. 1, 1862, pp. xxiv-v. and lxxxvi-vii.	Carré's.
1862	Traitement direct des eaux de la mer concentrées par l'emploi du froid artificiel à très-basse température.—*Ibid.*, Rapport par M. Balard, v. 1, 1862, pp. 192–96.	Carré's.
1862	Machines à glace.—*Ibid.*, Rapport par M. Lan, v. 6, 1862, pp. 341–44.	Various.
1862	New ice-machine.—Mech. M., new s., v. 8, 1862, p. 198.	Lespine's.
1862	Welches sind die zweckmässigsten Apparate zur Eisfabrikation?—Deut. Ind.-Z., 1862. p. 550.	Various.
1862	Artificial ice.—Builder, v. 20, 1862, p. 272.	Various.
1862	Siebe's refrigerating apparatus.—Eng., v. 14, 1862, pp. 275–76.	Siebe's.
1862	Rapport sur un appareil de M. Carr ayant pour objet la production du froid artificiel. (Commission composée de MM. Regnault, Balard, Pouillet rapporteur.)—Compt. r., v. 54, 1862, pp. 827–39.—Cop. in Bull. S. d'Enc., 1863, pp. 32–47 and pl. 262 and 263.—Trans. in Pr. Mech. J., 2nd s., v. 8, 1863, pp. 170–72 and 203–4.—Also in Pol. J., v. 168, 1863, pp. 171–85 and pl. 111.—Also in Pol. C., 1863, pp. 883–86 and pl. 25.	Carré's.
1862	Fabrication de la glace et du froid au moyen de	Tellier's.

Date of Publication.	Titles.	Inventions chiefly referred to.
	l'éthylamine et de la méthylamine; par M. Tellier.—Compt. r., v. 54, 1862, pp. 1188–89.—Trans. in Pol. J., v. 165, 1862, pp. 450–51.—Cop. in Gew. Württ., 1862, p. 489.	
1862	Ice-making, freezing, and cooling machines.—D. K. Clark's Exhibited Machinery of 1862 (1864), pp. 277–78.	Various.
1863	Ice-making machinery.—Pr. Mech. J., 2nd s., v. 8, 1863–4, pp. 5–9.—Trans. in Pol. J., v. 168, 1863, pp. 434–36 and pl. VII.—Also in Pol. C., 1863, pp. 1087–89 and pl. 29.	Harrison and Siebe's.
1863	Procuring ice in India by mechanical means. By J. Sked.—Pr. Mech. J., 2nd s., v. 8, 1863–4, p. 20.	——
1863	Extraction of the potashes from sea-water with Carré's apparatus. — Richardson and Watts' Chemical Technology, 2nd ed., v. 1, pt. 3, 1863, p. 545.	Carré's.
1863	De la production du froid.—Applications industrielles.—Appareils Carré. Par F. d'Auriac. Paris. 1863.	Carré's.
1863	Fabrication industrielle de la glace, par M. Carré. —Description des appareils construits par MM. Mignon et Rouart. Par Ernest Saint-Edme.—Port. éc., 1863, col. 32–37.	Carré's.
1863	Die Maschinen zur Darstellung des Eises.—Arbeitgeber, 1863.—Cop. in Pol. J., v. 167, 1863, pp. 396–97.	Various.
1863	Ueber Apparate zur Eisbereitung.—Arbeitgeber, 1863.—Cop. in Pol. C., 1863, p. 902.	Harrison's.
1863	Die Eismaschine.—Gew. Württ., 1863, pp. 75–78.—Cop. in Pol. C., 1863, pp. 544–46.	Various.
1863	Ueber Eisbereitung und über die Apparate für diesen Zweck, welche auf der Londoner Ausstellung waren. Von Dr. H. Grüneberg in Kalk bei Köln.—Monatschrift des Gewerbevereins zu Köln, 1863, p. 22.—Cop. in Pol. C., 1863, pp. 655–61 and pl. 19.	Carré's, Siebe's, & Lawrence's (maker).
1863	Refrigerating or freezing apparatus. Alex. Carnegie Kirk, patentee.—Pr. Mech. J., 2nd s., v. 8, 1863–4, pp. 113–14 and 149, and pl. 302.—Trans. in Pol. J., v. 170, 1863, pp. 241–45 and pl. IV.—Also in Pol. C., 1864, pp. 50–53 and pl. 3.	Kirk's.
1863	Carré'sche Eisapparat.—Verhandlungen des Vereins zur Beförderung des Gewerbfleisses in Preussen, 1863, p. 28.	Carré's.
1863	Ueber die Carré'schen Eisapparate. Mitgetheilt von Dr. R. Weber.—*Ibid.*, 1863, pp. 118–26, and pl. XIII. and XIV.	Carré's.
1863	Die Gesetze der Eisfabrikation und die dabei gebrauchten Maschinen. Von dem Civ.-Ing. Dr. Rob. Schmidt zu Berlin.—Ann. Land., 1863, pp. 275–77 and 284–85.	Various.
1863	Kirk's Abkühlungs-Apparat oder Eismaschine.—Deut. Ind.-Z., 1863, p. 459.	Kirk's.
1863	Carré's refrigerating and freezing.—Eng., v. 16, 1863, pp. 214–16.	Carré's.

Date of Publication.	Titles.	Inventions chiefly referred to.
1863	Die Eismaschinen von Carré und Siebe. Von Prof. Heeren.—Mittheilungen des Gewerbe-Vereins für das Königreich Hannover, 1863, pp. 167–82 and pl. V.	Carré's and Siebe's.
1863	Eisapparat von Carré.—Zeit. V. d. Ing., 1863, p. 222.	Carré's.
1864	On a machine for producing cold by the expansion of air. By Mr. Alex. C. Kirk, As. I. N. A.—Transactions of the Institution of Engineers in Scotland, v. 8, 1864–5, pp. 14–35 and pl. I.	Kirk's.
1864	Production du froid artificiel.—Appareil industriel continu pour fabriquer la glace et appareil domestique intermittent. Par MM. Carré et Cie et construits par MM. Mignon et Rouart, à Paris.—Publ. ind., v. 15, 1864, pp. 453–72 and pl. 37.	Carré's.
1864	Production of cold by the expansion of air.—Eng., v. 18, 1864, p. 222. (Paper read by Mr. A. C. Kirk before the British Association in 1864, and not published in its Reports.—See following entry.)	Kirk's.
1864	Production of cold by the expansion of air. By Mr. A. C. Kirk.—Mech. M., new s., v. 12, 1864, pp. 245–46. (Read before the British Association in 1864.—See preceding entry.)—Trans. in Pol. J., v. 174, 1864, p. 399.	Kirk's.
1864	Kirk'sche Eismaschine.—Deut. Ind.-Z., 1864, p. 498.	Kirk's.
1864	Fabrication de la glace et du froid au moyen de l'éthylamine et de la méthylamine. Par M. Tellier.—Tech., v. 25, 1864, pp. 634–35.	Tellier's.
1864	Ueber die in der neueren Zeit in Vorschlag gebrachten und zur Anwendung gekommenen Eiserzeugungsapparate.—Zeit. V. d. Ing., 1864, pp. 639–58 and pl. XVII.	Various.
1865	Eismaschine.—Deut. Ind.-Z., 1865, p. 385.	Ménard's.
1865	Eismaschine.—Deut. Ind.-Z., 1865, p. 407.	Tellier's.
1865	Tellier's Eiserzeugungsmethode.—Deut. Ind.-Z., 1865, p. 424.	Tellier's.
1865	Sur la production artificielle du froid par les appareils Carré. Par M. Rouart.—Mém. S. Ing. c., 1865, pp. 420–22. (Paper in full published in 1868.—See below.)	Carré's.
1865	La production artificielle du froid par les appareils Carré. Note de M. Rouart. (Compte-rendu de la séance du 3 nov. 1865 de la Société des Ingénieurs civils.)—Ann. G. civ., 1865, pp. 835–36. (See preceding entry.)	Carré's.
1866	Refrigerating machines.—Engng., v. 1, 1866, p. 62.	Kirk's.
1866	Kirk's refrigerating machine.—Engng., v. 1, 1866, p. 124.	Kirk's.
1866	Glacière domestique à vapeur d'eau de M. Toselli—Mondes, v. 10, 1866, p. 331 and 668–71.	Toselli's.
1866	Die Kosten der Eisbereitung mittelst der Maschinen von Carré und Siebe. (Aus einem Vortrage des Hrn. Assistent Wegler in einer Versammlung des Nürnberger Gewerbevereins.) — Pol. J., v. 182, 1866, pp. 245–46.—Cop. in Deut. Gew., 1866, p. 402.—Also in K.-u. Gew.-Bl. 1867, pp. 42–44.	Carré's and Siebe's.

Date of Publication.	Titles.	Inventions chiefly referred to.
1866	Machine à faire la glace.—Mondes, v. 12, 1866, pp. 142–43.—Trans. in Deut. Ind.-Z., 1867, p. 26.	Tellier's.
1866	Ice.—Tomlinson's Cyclopædia of Useful Arts, v. 3, Appendix, 1866, pp. 410–18.	Various.
1867	L'ammoniaque dans l'industrie par Ch. Tellier. 2nd ed. Paris, 1867.	Tellier's.
1867	Freezing.—Ure's Dictionary of Arts, Manufactures, and Mines, 6th ed., v. 2, 1867, pp. 398–402.	Various.
1867	Appareil Carré.—Privat-Deschanel et Focillon's Dictionnaire général des Sciences, pt. 2, 1867, pp. 1214–16.	Carré's.
1867	Production of cold by M. Carré's apparatus.—Richardson and Watts' Chemical Technology, 2nd ed., v. 1, pt. 5, 1867, pp. 296–99.	Carré's.
1867	Kirk's refrigerating apparatus.—*Ibid.*, 2nd ed., v. 1, pt. 5, 1867, pp. 299–303 and pl. 3.	Kirk's.
1867	Glacière à vapeur d'eau de M. Toselli. Par F. Moigno.—Mondes, v. 13, 1867, p. 147.—Trans. in Pol. J., v. 184, 1867, p. 408.	Toselli's.
1867	Ueber die Kosten der Eisbereitung mittels der Maschinen von Carré und Siebe.—Pol. C., 1867, pp. 137–38.	Carré's and Siebe's.
1867	Eisapparat.—Deut. Ind.-Z., 1867, p. 308.	Carré's.
1867	Sur de nouveaux générateurs de froid. Note de M. Ed. Carré.—Compt. r., v. 64, 1867, p. 897–98.—Trans. in Pol. J., v. 185, 1867, pp. 77–79.	Carré's.
1867	Ueber Tosseli's Eisapparat.—Pol. J., v. 185, 1867, pp. 244–45.	Toselli's.
1867	Froid artificiel.—Ann. G. civ., 1867, pp. 398–99.	Carré's.
1867	Glacière à vapeur d'eau de M. Toselli.—Mondes, v. 14, 1867, pp. 248–49.	Toselli's.
1867	Fabrication de la glace.—Exposition Universelle de 1867.—Rapports du Jury international, Introduction par M. Michel Chevalier, v. 1, 1868, pp. xciii–viii, and Rapport par M. Arnould Thénard, v. 8, 1868, pp. 367–77.—This last report cop. in Gén. ind., v. 40, 1871, pp. 141–45.	Carré's (both).
1867	Production industrielle du froid. Par M. H. Dufrené, ing. civ.—Études sur l'Exposition de 1867. Par MM. les Rédacteurs des *Annales du Génie civil*, 2nd s., pp. 124–35 and pl. XLIV.—Also published separately.	Carré's and Tellier's.
1868	Eisapparat.—Deut. Ind.-Z., 1868, p. 8.	Carré's.
1868	Artificial freezing and refrigeration. By B. H. Paul, Esq., Ph.D.—J. Soc. Arts, v. 17, 1868–9, pp. 67–76.—Letters from Ch. E. Flower, pp. 95–6, Benj. H. Paul and T. King, Eng., 1869, pp. 107–8, Ch. E. Flower, pp. 119–20, and Siebe Brothers and B. H. Paul, pp. 135–36.	Various.
1868	Die Eismaschine von Oscar Kropff u. Comp. in Nordhausen. — Pr. Masch.-C., 1868, p. 185. (Kropff, maker.)	(?)
1868	Edmond Carré's Luftpumpen—Eisapparat.—Deut. Gew., 1868, pp. 316–17.	Carré's.
1868	Note sur les appareils à produire le froid. Par M. H. Rouart.—Mém. S. Ing. c., 1868, pp. 190–	Carré's.

Date of Publication.	Titles.	Inventions chiefly referred to.
	205. (See two abstracts amongst entries in 1865.)	
1868	Ice-making machines.—Engng., v. 6, 1868, pp. 483–85.—Cop. in Sc. Am., new s., v. 20, 1869, p. 68.—Also in Am. Art., new s., v. 8, 1869, p. 4–5.—Trans. in Pol. J., v. 191, 1869, pp. 189–96 and pl. V.	Siebe's.
1868	Refroidissement des brassins, par le nouveau appareil de M. Ch. Tellier. Par Ch. Mène.—Journal de l'Agriculture, v. 2, 1868, pp. 556–57.	Tellier's.
1868	Appareil pour refroidir les brassins et faire de la glace, par M. Ch. Tellier. Par Ch. Mène.—*Ibid.*, v. 3, 1868, pp. 795–96.	Tellier's.
1869	Calculation of the amount of ice which can be produced from a given amount of coal in the modern ice-machine. By P. H. Van der Weyde, M.D.—Sc. Am., new s., v. 21, 1869, p. 91.	——
1869	Invention for the preservation of meat, fish, etc., by means of refrigerated air. By Wm. Shand.—J. Soc. Arts, v. 17, 1869, pp. 97–99.	Tellier's.
869	Eismaschinen.—Deut. Ind.-Z., 1869, pp. 187–88.—Cop. in Pol. C., 1869, pp. 1267–68.	Carré's.
1869	Can artificial ice successfully compete with natural ice. By P. H. Van der Weyde, M.D.—Am. Art., new s., v. 8, 1869, pp. 402–3, and v. 9, 1869, p. 2.	——
1869	Making ice by machinery.—Manufacturer and Builder, 1869, pp. 353–54.	Weyde's.
1869	Maschine zur Bereitung von Eis mittelst Dampf und Petroleum.—Pr. Masch.-C., 1869, p. 222.—Cop. in Ann. Land., 1869, p. 365.	Weyde's.
1869	Eismaschine.—Deut. Ind. Z., 1869, p. 338.	Weyde's.
1869	Anwendung der Carré'schen Eisbereitungs-Maschine in den Brauereien.—Pol. J., v. 193, 1869, p. 432.—Cop. in Ann. Land., 1869, p. 365.	Carré's.
1869	The artificial production of ice and cold. By Dr. B. H. Paul.—Quarterly Journal of Science, 1869, pp. 197–209.—Cop. in Mech. M., new s., v. 21, 1869, pp. 390 and 402–3.—Also published separately. London, 1869.—Trans. in Mon. sc., 1869, pp. 479–87.	Various.
1869	Reece's Eismaschine.—Deut. Ind.-Z., 1869, p. 465, and pl. XIII.—Cop. in Pol. J., v. 195, 1870, pp. 40–41 and pl. I.—Also in Pol. C., 1870, pp. 330–31 and pl. 10.	Reece's.
1869	Freezing and ice-making machine.—Mech. M., new s., v. 22, 1869, pp. 387–89.—Trans. in Pol. J., v. 195, 1870, pp. 115–18 and pl. II.—Cop. in. Pol. C., 1870, pp. 468–72 and pl. 14.	Windhausen's.
1869	Auf welche Weise Paris mit Eiswasser im Sommer versorgt wird.—Ausland, 1869, p. 864.	——
1870	Eismaschine von Fr. Windhausen, Civilingen. in Braunschweig.—Deut. Ind.-Z., 1870, pp. 2–3 and pl. I.	Windhausen's.
1870	Eismaschine.—Deut. Ind.-Z., 1870, p. 38.	Mack's.
1870	Die Eisfabrication für Bierbrauerein. Von Dr. R. Schmidt in Berlin.—Schweizerische polytechnische Zeitschrift, 1870, p. 62.	Carré's.

Date of Publication.	Titles.	Inventions chiefly referred to.
1870	Die Eismaschine für grössere Eisquantitäten und mit kontinuirlichem Betriebe in der Eisfabrik von A. Pokorny in Wien. Von Frabriksdirektor Matscheko. — Zeitschrift des österreichischen Ingenieur-Vereins, 1870, pt. 1.—Cop. in Deut. Gew., 1870, pp. 121–22.	(?)
1870	Kosten des künstlichen Eises.—Deut. Ind.-Z., 1870, p. 155.	Carré's.
	Ueber die Wärmeentziehung bei niedrigen Temperaturen durch mechanische Mittel. Von C. Linde.—Bay. I.-u. G.-Bl., 1870, pp. 205–10, 321–26, and 363–67.—Abstract in Ch. C.-Bl., 1871, p. 207.	Carré's, Siebe's, and Windhausen's.
1870	Siebe Bros.', Engineers (Works, Mason Street, Lambeth), patent improved direct-acting ice-making machine.—With steam engine fitted to a vertical steam boiler.—Pr. Mech. J., 3rd s., v. 5, 1870, p. 251 and pl. XIV.—Trans. in Gén. ind., v. 40, 1871, pp. 141–47 and pl. 509.—Also in Pol. J., v. 195, 1870, pp. 522–23 and pl. IX.—Also in Pol. C., 1870, pp. 840–41 and pl. 24.	Siebe's.
1870	Notizen über Eisfabrication; von Dr. Rob. Schmidt, Civiling. in Berlin.—Pol. J., v. 195, 1870, pp. 523–25.—Cop. in Pol. C., 1870, pp. 857–58.	Carré's.
1870	Improved freezing machine.—Mech. M., new s., v. 23, 1870, pp. 189–90.—Trans. in Pol. C., 1870, pp. 902–4 and pl. 26.—Also in Deut. Gew., 1870, pp. 247–48.—Also in Pol. J., v. 197, 1870, pp. 511–12 and pl. VI.	Mort and Nicolle's.
1870	Latest improvement in ice machines.—Engineering and Mining Journal, 3rd s., v. 9, 1870, p. 257.	Weyde's.
1870	The Tellier ice machine.—Sc. Am., new s., v. 23, 1870, pp. 295–96.	Tellier's.
1870	Zur künstlichen Kälteerzeugung.—Deut. Ind.-Z., 1870, pp. 310–11.	Various.
1870	Ueber künstliche Kälteerzeugung durch Compression und Expansion der Luft; von Berginspector H. Bruhn in Stassfurt.—Pol. J., v. 197, 1870, pp. 20–22.—Cop. in Pol. C., 1870, pp. 1356–58.—Also in Deut. Gew., 1870, p. 367.	Windhausen s.
1870	Manufacture of ice.—Am. Art., new s., v. 10, 1870, pp. 89–90.	Various.
1870	Windhausen's freezing machine.—Engng., v. 10, 1870, p. 133.	Windhausen's.
1870	Refrigerative effects of the Carré ice machine.—J. Fr. Inst., 3rd s., v. 60, 1870, pp. 156–58.	Carré's.
1870	Improved apparatus for refrigerating beer and other liquids and for making ice.—Mech. M., new s., v. 24, 1870, pp. 404–5.—Trans. in Pol. J., v. 199, 1871, pp. 362–63 and pl. X.	Mignot's.
1870	Appareils à produire la glace.—Mon. sc., 1870, pp. 838–39.	Various.
1871	Vergleichung der Herstellungskosten des künstlichen Eises bei der Fabrication einerseits mittelst einer Carré'schen, andererseits mittelst einer Windhausen'schen Maschine. (Von	Carré's and Windhausen's.

Date of Publication.	Titles.	Inventions chiefly referred to.
	Dr. R. Schmidt in Berlin.)—Pol. J., v. 199, 1871, pp. 38–40.—Cop. in Deut. Ind.-Z., 1871, pp. 45–46.—Cop. in Pol. C., 1871, pp. 264–65.	
1871	Ueber die Wirkung von Eismaschinen. Nach Prof. C. Linde.—Deut. Ind.-Z., 1871, p. 55.—Cop. in Pol. J., v. 199, 1871, pp. 361–62.—Abstract in Ch. C.-Bl., 1871, p. 207.	Various.
1871	The abstraction of heat by mechanical means. By Mr. Rob. Morton, of Stockton.—Proceedings of the Cleveland Institution of Engineers, Jan. 12th, 1871, pp. 12–26 and pl. III., IV., and V.—Discussion, Feb. 9th, 1871, pp. 10–11.	Various.
1871	Verbesserte Eis- und Kühlmaschine. Von C. Linde.—Bay. I.- u. G.-Bl., 1871, pp. 264–72.	Various
1871	On the artificial production of cold. By Prof. John Gamgee.—J. Soc. Arts, 5th May, 1871.—Trans. in Mon. sc., 1871, pp. 470–76.	Various.
1871	Reece's ice-making and cooling apparatus.—Mech. M., new s., v. 26, 1871, p. 35.—Trans. in Pol. C., 1871, pp. 1234–35 and pl. 37.	Reece's.
1871	Die Eis-resp. Kälteerzeugungs-Maschine nach Franz Windhausen's Patent. Von A. Metz.—Bay. Bierbr., 1871, pp. 140–43.—Cop. in Pol. C., 1871, pp. 1519–20.	Windhausen's.
1871	Kirk's refrigerating machine.—Engng., v. 12, 1871, pp. 70–72.	Kirk's.
1871	Ice manufacture.—Engng., v. 12, 1871, pp. 179–80.	Tellier's.
1871	Ice manufacture.—Engng., v. 12, 1871, p. 231.	Various.
1871	La production du froid. Par Ernest Saint-Edme.—Annales industrielles, v. 3, 1871, pp. 821–26.	Tellier's.
1873	Ice-making machine.—Spon's Dictionary of Engineering, division vi., 1873, pp. 1996–2002.	Various.
1873	Eis-resp. Kaltluft-Maschine.—Pr. Masch.-C., 1873, pp. (?) and pl. 65 and 70.	Windhausen's.
1873	Ice-making machinery at the Vienna Exhibition.—Engng., v. 16, 1873, pp. 346–48.	Various.
1874	The artificial production of low temperatures. By Prof. Edwin J. Houston.—J. Fr. Inst., 3rd s., v. 67, 1874, pp. 9–11.	Windhausen's.
1874	The aqua-ammonia ice-making machine.—Iron, v. 3, 1874, p. 172. (Vaas and Littmann, makers.)	(?)

Mr. SIEMENS said if he wished to be critical he might find fault with the title of the Paper. The Author spoke of a machine for "the production of cold." Cold was the absence of heat, and it might be open to question whether it was possible to produce the absence of a thing. Refrigeration, which he thought the preferable word, meant the transfer of heat from one substance to another of the same or a superior degree of temperature, and the Author evidently agreed in that definition. The subject was one of considerable interest at the present time. Refrigerating machines were now largely used in breweries, since fermentation went on to advantage only at a temperature a little above freezing point; and to attain that point during all seasons of the year rendered artificial means of maintaining a low temperature necessary, unless native ice was employed for the purpose. For preserving meats also in hot climates and transporting it, artificial means of reducing the temperature were coming into use, and would be more extensively employed if a cheap and ready method could be devised. Refrigeration was of great importance in hot climates in a sanitary point of view, and the time was not distant, he thought, when houses and places of public resort would be refrigerated with the same care and regularity as they were now heated when necessary. He believed this might be accomplished at a cheap rate. It was stated, in the Paper, and it was an undoubted scientific fact, that mechanical refrigeration might be obtained at a cheaper rate if the reduction of temperature required were only slight than if it were considerable. Thus, an air-machine producing ice would work much less economically than one producing only cool air. In order that the subject might be more fully opened out for discussion, he proposed to refer shortly to the different methods that had been devised for producing refrigeration. There were four methods in use. The first was the old system by the evaporation of alcohol, ether, or other volatile substances. Even water when allowed to evaporate under a current of air produced refrigeration. Alcohol did so to a greater extent, and ether to a still greater extent. This method had been adopted, perhaps, for centuries; but in recent times it had been improved by Siebe and by Harrison, who had contrived that the vapour produced by evaporation should not be lost, but that it should be mechanically compressed and condensed, in order to serve over and over again. The method of producing the reduced temperature was the same in both cases, but instead of losing the ether or alcohol, a certain amount of power was expended in the improved arrangement. Another method was the chemical one of pro-

ducing refrigeration by evaporation in connection with absorption. Many vapours—ammonia being one of them—were readily absorbed by water, but could be separated again by the application of heat to the mixed liquid. A machine on that principle was shown at the Universal Exhibition, in 1851, by M. Carré, and very good results had been realised by it. It consisted of a boiler which was filled with ammoniacal liquor, and the ammonia vapour was driven off under considerable pressure into a surface condenser composed of tubes surrounded by cool water. A separation was thus effected by heat of the ammonia from the water; and the ammonia, after being withdrawn into a vessel of lower pressure, evaporated at a very low temperature, and thus produced refrigeration, the vapours of ammonia being eagerly absorbed by water of ordinary temperature forming mother liquid for re-evaporation in the boiler. The machine was largely used, especially on the Continent; and, from information he had received, it produced a hundredweight of ice at the expense of about a shilling. An ingenious modification of this machine for small applications on board ship or for household use had been devised, consisting of two vessels connected by a pipe, but hermetically sealed. One of the vessels contained the mother liquid, which was alternately heated and cooled, to drive off the ammonia, and to re-absorb it from the second vessel, which served alternately as condenser and refrigerator for the production of ice. Another method was by the solution of crystalline substances. There were various refrigerating mixtures, one of the salts so employed being carbonate of ammonia, and another chloride of calcium. When crystals of chloride of calcium were dissolved in water, a considerable reduction of temperature—about 30° Fahrenheit—took place. Although that would not be sufficient to produce ice from water of 60° or 65° temperature, an arrangement could be made by which the water to be cooled exchanged heat with the spent liquor, thus producing an accumulation of the effect in the centre of the machine. He constructed a machine on this principle many years ago, which produced ice at a considerable rate, but the salt employed—chloride of calcium—was not a pleasant substance to deal with. It had to be re-evaporated and crystallised, and this process was inferior to the purely mechanical methods which had since been adopted. The most perfect of these, as regarded cleanliness and freedom from loss, was the air machine. Atmospheric air was compressed to one half, or one atmosphere above atmospheric pressure. The compressed air was allowed to cool in contact with water, either by external application or by injection,

and to expand again in a working cylinder. The amount of heat that disappeared in the second working cylinder was the exact measure of the refrigeration produced, and it could be easily calculated; whereas the power expended was the difference of force involved in compressing the air at a higher and of expanding it at a lower temperature. In 1857 a machine of that description was invented by Dr. Gorrie, an American, and was brought to London. Mr. Siemens was asked to report upon it. The machine did not produce satisfactory results. The engine was a good one, and the air-pump was judiciously constructed; but the connection between the reservoir containing the compressed air and the air-expansion engine was too narrow, and was provided with a throttle valve, there being evidently a vague idea in the mind of the inventor that the air would produce more refrigeration in expanding spontaneously without doing work than in expanding behind a working piston, an idea which was permissible at that time when the dynamical theory of heat was little understood. That was one of the defects which he pointed out. Another was that the hot or compressed air was not sufficiently cooled before it was expanded, and was not deprived of its moisture. The moisture in air played a considerable part in those machines. At a temperature of 65° Fahrenheit saturated air contained 1 per cent. of vapour of water, and this had not only to be reduced into the liquid, but also into the solid condition, representing a total absorption of heat to the amount of 1,140 units of heat per lb. of condensed vapour, which, upon the quantity of air, would represent 15° Fahrenheit of loss in the effect produced by the expansion. He believed, if these faults had been remedied, the machine would have given satisfactory results. Since that time a German engineer, Mr. Windhausen, had constructed machines on similar principles, and had, after many fruitless attempts, obtained remarkable results. It was stated, at a meeting in connection with the Vienna Exhibition, that a machine of 150 HP. produced 30 cwt. of ice per hour, the theoretical result being that that amount ought to be produced by 90 HP. The cost of producing a hundredweight of ice by this machine was stated to be one shilling—a similar result to that obtained in M. Carré's machine. The machine described by the Author of the Paper was also an air machine—a reversed air-engine, so to speak—and therefore, in a certain sense, analogous to those he had before mentioned. The Author did not compress the air, cool it, and then transfer it into a separate cylinder to be re-expanded, but he combined these

operations in an engine similar, in every way, to Stirling's air-engine, on a supposition that that was the most perfect air-engine known, and that, in inverting it, he would be likely to obtain the best result of refrigeration. He could not, however, agree in the opinion that the Stirling engine was a perfect one. It was the first engine containing a regenerator; but (as he had pointed out in a Paper read before the Institution in 1853) it realised at most only from one-fifth to one-sixth part of the theoretical duty of the heat expended. The reason was that all the air cooled and heated alternately did not enter the working cylinder; but the diagram of the force obtained in the working cylinder formed only a sixth part of the diagram that would be produced if the whole of the air were allowed to expand behind a working piston and between the same limits; and that proportion really indicated the dynamic value of the engine. Therefore, although he admired the ingenuity with which the Author had enlarged the available heating surfaces of Stirling's arrangement, and elaborated the best form of regenerator for the purpose, he could not agree in the application of that principle to refrigeration. He believed better results would have been obtained if the compressing apparatus had been separated from the expanding apparatus as had been done by others. That opinion appeared to be corroborated by the results given in the Paper. With 37 HP. 20 gallons of water were reduced from 61° to 47¼° per minute, which was equal to 2·8 lbs. of ice per hour, whereas the Windhausen engine was said to produce 20 lbs. of ice with 1 HP. Generally speaking, he believed the air-compressing engine, on the purely mechanical mode of producing refrigeration, was applicable with the greatest advantage where moderate refrigeration was required. Where the production of ice in large masses was desired, he believed the method adopted by Siebe and by Harrison was superior, for this reason: in compressing and expanding air, 25,000 cubic feet of air were required to produce the effect of 1 lb. of ice; whereas, in compressing sulphuric ether after evaporation, only 5,100 cubic feet were required, the reason being that when sulphuric ether was transferred from the liquid into the gaseous condition, the whole of the latent heat was obtained. A much higher result was arrived at by using a still more volatile substance —methylic ether—which at a depression of temperature equal to 15° Centigrade had a pressure of 1½ atmosphere, and the displacement of piston to produce the same effect was only about 340 cubic feet. Therefore a pumping-engine, with a displacing capacity of piston of 340 cubic feet per minute, would produce

the same effect as an air engine of 25,000 cubic feet displacement per minute, and of 5,000 cubic feet in the case of a sulphuric ether engine. This meant a much smaller engine and a less costly machine in the case of the methylic ether pump, although the expenditure of power might be the same; but, on the other hand, there was the set-off of having to deal with a highly inflammable material like methylic ether instead of with atmospheric air. For producing a depression of temperature in houses or breweries he believed the air-engine was the best contrivance that could be adopted.

Mr. H. J. West said, though the Paper was on the mechanical production of cold, it only gave a description of apparatus invented by the Author. It was a matter for regret that the subject was not more extended, so as to embrace other kinds of air machines, and the class of apparatus in which cold was mechanically produced by the evaporation of water, ammonia, or ether. The scope of the discussion was narrowed by the omission of all reference to the work done by the ether machine at Bathgate, or by other descriptions of machinery, or by comparison between such and the Author's engine. The Author had stated that the inflammability of ether was one of the reasons why the machine at Bathgate was disused. The late Mr. D. E. Siebe and himself had often remarked upon the circumstance that the ether machine, which it was admitted had done good service, was in constant work up to the time when Mr. Kirk introduced his apparatus, when the inefficiency of the ether machine appeared to become discernible. He was glad now, after the Author's statement, to be able to correct that impression. With regard to the objection on the ground of the inflammability of ether, he might remark that paraffin was inflammable, and so was alcohol, yet the one was burned and the other was drunk. Coal gas was inflammable, but that was no objection to its use even near a fire. In the ether apparatus manufactured by his firm (of which there were fifty or sixty in use in breweries, paraffin, and oil works), it was a common practice to test the joints by a lighted candle. The injection of water and brine into the hot and cold ends of the cylinder was not, as claimed by the Author, a new improvement, but had been included in previous patents.[1] As a refrigerative agent, ether possessed great advantages over the air system, for these reasons: to produce cold by air it was necessary first to compress the air to 50 lbs. to 100 lbs. on the square inch,

[1] Newton's specification, No. 13,234—1850.
Mignot's „ No. 1,579—1870.

and then to cool it previous to expansion; but cold was at once obtained by the simple expansion of ether vapour, and the preliminary processes of high compression and cooling, as in the case with air, were consequently avoided. In the trial of the machine at Oak-bank the horse-power indicated was 37, and the quantity of water cooled per minute was 20·6 gallons, or 1,236 gallons an hour, 14°. The quantity of cooling or condensing water was about equal to the amount cooled in the engine—a far too large amount to be used for the purpose. With some of the machines of his firm, now in use in large breweries, more than six times the amount of work done by the machine at Oak-bank could be accomplished by 50 or 60 HP. The brewers complained of even that amount of power being expended; but how much more would they complain of 122 HP., which Mr. Kirk's machine would require for the same duty? Such a heavy fuel tax and expenditure of force, as compared with the results obtained, would prohibit their further use. The Author had displayed great ingenuity and ability in the construction of his apparatus, and, with some modification, it would be one of the best air machines in use.

Mr. Imray said, in looking at the figures given with regard to the dry-air machine, it appeared that in heating the cooling water applied to it what might be called 1,376 Joule's equivalents were effected, *i.e.*, 1,376 lbs. of water heated one degree. This, according to the ordinary estimate of 772 feet of work done per lb. degree of water heated, would give a power of 32 horses. Again, he extracted from the brine an amount of heat equivalent to 549 lbs. of water cooled 1°, which, reckoned according to Joule's equivalent, gave 13 HP. The difference between this cooling of the brine and the heating of the cooling water amounting to 19 HP., was what the engine did; and, considering that it was working at 23 HP., there appeared to be 83 per cent. of efficiency. Taking the figures in the same way with the wet machine the efficiency was only 40 per cent. As 1 lb. of coals in an ordinary boiler would boil off 10 lbs. of water, it ought to produce 234 HP.; but 1 lb. of coals, with the best engine working with $2\frac{1}{2}$ lbs. of coal per HP. per hour, would only give 60 HP. instead of $2\frac{1}{2}$ times 234, *i.e.*, only 10 per cent. of the heat put into the water. The greater part of the heat was wasted, going off as latent heat with the waste steam. A machine giving 83 per cent. of efficiency from the working of a piston would be a most valuable one. He regretted Mr. West had not given such data with regard to his ether machine as would enable a comparison to be instituted

between the two. The ether machine ought to be better than the other, because in condensing ether the pressure was got rid of altogether when it attained the liquid state. He was surprised at the statement that 1 cwt. of ice could be produced for 1*s*. That meant, taking water at 52°, that it was reduced 20°, and 140°, the latent heat of ice, altogether 160°, which was equal to 18,000 Joule's equivalents; and that, according to the usual reckoning, would require 1·8 lb. of coal to produce it. That was a large efficiency indeed. He did not question the statement, but should be glad to know how the efficiency was obtained.

Mr. L. Olrick said he had notes of some careful experiments made at Truman's brewery by the engineer, Mr. King. From these it would appear that eighteen barrels of water, each weighing 360 lbs., were cooled 10° by using 4 cwt. of ice. Each pound of ice, in being converted into water of a final temperature of 51°, absorbed 161 units of heat; and 4 cwt., or 448 lbs., multiplied by 161, gave 72,300 units of total heat absorbed. Eighteen barrels of water, in cooling down 10°, would give off but 58,800 units, showing a deficiency of 13,500 units, which must have been absorbed by the vessel containing the water, or by the cooling effects of the atmosphere. Truman's machine could produce 6 tons of ice in twenty-four hours, or 5 cwt. per hour; in other words, it could cool twenty-two and a half barrels of "liquor" per hour 10°, or 81,000 lbs. 1° per hour. Comparing this result with that obtained when the machine was employed merely to cool water to be used in the ordinary refrigerators, Mr. King found that the machine was capable of reducing the temperature of twenty-six barrels of water hourly 23½°, or six hundred and eleven barrels 1°, that was to say, capable of absorbing 219,960 units of heat per hour. This gave an efficiency of 2·8 times as much as by making the ice first. Unfortunately there were no indicator diagrams taken from the engine that drove the machine, but the coal consumed to produce one ton of ice was 4½ cwt., which was equal to producing 4·44 lbs. of ice per lb. of coal. There was a difficulty in comparing different machines because the requisite data were not given. In some notes as to Mr. Siddeley's machine at Reid's brewery the indicated horse-power to drive it was 25, and thirty barrels were cooled per hour from 55° to 33°—*i.e.*, 3,960 lbs. 1° per minute. In the particulars of Mr. Kirk's machine no indicated horse-power was given, but his largest machine cooled forty-five barrels 15° per hour, or 4,050 lbs. 1° per minute. A French machine by M. Carré was said to produce from 8 lbs. to 15 lbs. of ice per pound of coal; but no data were given to check the

calculation. For every pound of ice 10 lbs. of water were required. In making ice he believed Mr. Kirk's machine was not so efficient as some others. At Messrs. Young's, at Bathgate, it only made 1 ton of ice per ton of coal used. During the last two years a machine by Mr. Reece appeared to be far more efficient than any other. According to experiments tried and reported upon by Professor Foster, 1,000 lbs. of ice were produced by a consumption of 50 lbs. of coal, and the water consumed was 4,000 gallons. The work was done in about three hours. Thus 20 tons of ice could be produced by 1 ton of coal. But the condensing water amounted to 800 tons, which seemed out of proportion to the quantity used by other machines. He did not approve of the title of the Paper, because in the majority of ice or refrigerating machines, as at present constructed, the power employed did not produce the cold, but only conveyed it, that was, took it out of one substance and forced it into another; hence the number of units of heat abstracted from, say water, might be many times greater than the number of units used to drive the engine. The number of units of heat abstracted should, however, be found in the water which the machine threw off. A common surface condenser with its circulating pump was a complete refrigerating machine to all intents and purposes; but the number of units of heat abstracted from the steam greatly exceeded the number of units employed to drive the circulating pump. The waste thrown out from refrigerating machines was twofold: exhaust steam from the engine, and hot water from the condenser. The smaller the collective cost of these two items for the work done, the better, of course was the machine.

Mr. Rees Reece said the machine devised by the Author was the most complete one of its class yet constructed; but he did not know why the mechanical production of cold as applied to air had been distinguished from that applied to ether, each being a method of producing cold by mechanical means. He could bear testimony to the efficiency of the machine at Bathgate, and he had also seen one of these machines of the same size at another place, where the results were practically the same. On the compressing side of the machine a quantity of heat was evolved, which was sufficient to heat 1,376 lbs. of water through 1°, and the compressed air in expanding cooled 609 lbs. 1°. The relation existing between 609 and 1,370 was the relation absolutely existing between the capacity for heat under constant volume and the capacity for heat under constant pressure. Reducing 1,376 into horse-power, it appeared that 32·2 HP. was exerted on the compressing side of

the machine; and 609, on the other side, would give 14·22 HP. Assuming the two engines to be working apart, 32·2 HP. was expended on the one side in compressing air, and on the other, 14·22 HP. was recovered back. The difference between these two would be the energy required to produce a given amount of refrigeration. In Mr. Kirk's machine 609 heat units was the amount of cold produced, and it was easy to arrive at the work that could accomplish as a refrigerating agent. He found in practice, and after considerable experience, that it took 200° of heat to freeze 1 lb. of water at 70°, allowing for waste of radiation. This would give just 3 lbs. of ice per minute, or 180 lbs. per hour. Taking 18 HP. of theoretical force, a perfect engine would give 10 lbs. per horse-power. Mr. Kirk had found the friction 5 HP. in excess of that—*i.e.* 23 HP. In that case the production would be 2·65 lbs. per minute per horse-power, or 159 lbs. per hour; or 7·3 lbs. per horse-power, friction included. The difference therefore between a perfect engine and the Author's results was as 7·3 is to 10. The conclusions arrived at by Mr. Siemens in reference to Windhausen's machine, differed from his observations. A large Windhausen machine working for some hours produced 560 lbs. of ice for every 96 indicated horse-power transmitted by the engine, being somewhat over 5·6 lbs. per horse-power. He did not think it would be possible to improve the air machine much beyond what had already been done, unless the relation existing between the capacity for heat under constant pressure and constant volume were wrong. The relation existing between 609 and 1,370 was as nearly as possible the relation existing between 1,424 and 424; and there was here a fair and substantive statement of mechanical equivalent of heat as applied to a perfect machine. In Mr. Kirk's machine the medium used was atmospheric air, and the mechanical energy was the means by which the cold was generated. But there were other methods by which mechanical energy could be used for the production of cold; such, for example, as the evaporation of liquids in what was wrongly called a vacuum. In evaporating a liquid by removing the atmospheric air, the vapour of the liquid became the substitute for that of the air. This might be said to be the nature of ether machines, so called, and the principle on which they were founded might be thus stated. Dalton found that the tension of the vapour of liquids was proportional to the distance of their boiling point in air, and the distance from which they were made to boil was the weight of the vapour which the pump was enabled to throw over. Taking water at 100° C. and ether at 35° C., the tension of their vapour would be the same, if evaporated

at 30° C. lower, that was the water at 70° C., the ether at 5° C. The tension of their vapour would then be ·3 of an atmosphere. Evaporating ether at 41° Fahr. by means of an air-pump, the tension of the vapour of ether, according to Dalton's law, and according to the direct experiments of M. Regnault, was ·3 of an atmosphere; and as a cubic foot of ether under ordinary pressure weighed 2·58 ounces, the weight of it at 41° would be as nearly as possible one avoirdupois ounce. Taking the same ether and evaporating it at 14° Fahr., that was at —10° C., the atmospheric pressure would be ·156 of an atmosphere, and the weight of the cubic foot would be exactly half an ounce. Evaporating at zero Fahr., the weight would be ·36 of an ounce. In the application of these figures to the evolution of heat by means of ether at various temperatures, with an air-pump of 10 feet cube, running at 40 revolutions a minute, 400 ounces of ether would be evaporated at 41°, 200 ounces at 14°, and 144 ounces at zero. A good deal had been said as to the difference caused by using ice for cooling directly and using water at an elevated temperature. The gain was that which he had stated. Evaporating the 400 ounces in the ether machine, taking the temperature of the condenser to be 85°, the first work of the machine was to reduce the temperature of the ether to 41°, which would require 14 per cent. of the whole ether. Reducing the temperature to 14°, it would take 22 per cent. of the whole ether, and reducing it to zero, 30 per cent.; so that an ether machine having an air-pump 10 feet, the double stroke running 40 per minute, the real and useful working would be as follows:—

Temperature.	Real evaporation.	Useful evaporation.
41° Fahr.	400 oz.	344 oz.
14° „	200 „	156 „
Zero	144 „	99·8 oz.

Taking a cylinder manufacturing ice at 14° and cooling water at 41°, the relative proportion of evaporation would be as 344 to 156.

He now came to another method of applying cold, independent of mechanical power. All that was required was to burn a given quantity of coal under a steam boiler, and the energy produced by that coal was the whole energy required. Mr. Philip Ferdinand Carré, fourteen or fifteen years ago, when engaged in the construction of ether machines, finding it difficult to carry them through, was led, after some researches of M. Regnault, to construct an ammonia, machine. Mr. Carré took a quantity of strong solution of ammonia, and boiled it over and into a condenser. He found, as others had done since, that 100 lbs. of strong solution of ammonia, boiled by a distillation up to 5 per cent., yielded

75 per cent. of ammonia, and 25 per cent. of water. This being condensed would be used effectively for refrigerating purposes. The only drawback was that the liquor condensed contained 25 per cent. of water, and holding a large quantity of ammonia made the machine intermittent and relatively costly, but not nearly so costly as an air or ether machine as a method of producing cold. The French Academy appointed a commission to investigate the subject, and that commission pointed out the want of complete success in the machine, stating that what was required was a method by which ammonia could be had nearly anhydrous on one side, and an exhaust liquor on the other free from ammonia. This led him to study the problem, and he would briefly state what he had done. By mixing two liquids together of different boiling points, one liquid could be separated thoroughly and perfectly from the other. When alcohol was mixed with water up to 5, 10, or 20 per cent., by a process of fractionation, the two could be separated; and it occurred to him that he could thoroughly remove the whole of the water contained in the mixture, and obtain on one side of the instrument ammonia free from water, and on the other side water comparatively free from ammonia. This he had been enabled to do, and the ammonia obtained in this way, passing through a condenser without the aid of any mechanical energy, was condensed simply by its own accumulation, and a current of cold water passing round it. Passing that ammonia into a refrigerator, he connected it to an absorbing vessel containing water or exhaust liquor; and simply opening a cock connecting them was sufficient for it to resume its aëriform condition, without the aid of any mechanical force, the gas being removed by its solution in the liquor of the absorbing vessel. In the case of the ammonia, the same as the ether, a portion of the work of the refrigerator was to reduce the temperature of the ammonia from that of the condenser to that of the refrigerator at its working temperature. Instead, as in the case of the ether, using from 14 per cent. to 30 per cent., he found, in reducing it to 41° he used 2½ per cent., in reducing it to 14° 4 per cent., to zero 5 per cent. For every lb. of ammonia thus liquefied in the liquefactor, 920° of heat were given out, *i.e.*, it heated 920 lbs. of water through 1°. In the evaporation of the same quantity of ammonia it cooled down 920 lbs. of water through 1°. At whatever temperature it worked the cost of refrigeration was the same; by means of ammonia, therefore, cold could be produced at the cheapest possible rate. The relation existing between ammonia and ether was the relation between 168 and 920, irrespective of the mechanical energy required. There was one other advantage in

the use of ammonia. When the temperature of the cooling cylinder was reduced 30 below zero, it had still a mechanical energy and force equal to that of water at 212, and going down further, 10, 15, 20, 30, 40, 50, and even a temperature of 60 degrees below zero of Fahr., it would be as energetic an instrument as at any higher temperature, whilst all others deteriorated in efficiency as the temperature fell. Taking a pound of coal and burning it clean under the same boiler, 8,500 heat units would be transmitted to the water. Using that to work a good air machine, 200° of heat would be absorbed; in the ether machine, 600°; in the ammonia machine, 4,000°. These differences showed the real economy of the different systems. It was essential that the machines, whatever system was adopted, should be well constructed.

Mr. David Thomson said, when he first had occasion to pay attention to this subject two or three years ago, he found much difficulty in getting reliable, and practically available, information on the theory of the production of cold by mechanical means, without understanding which it was impossible to ascertain in what direction improvements might be looked for, or to estimate to what extent they might be carried. Even during the present discussion little had been said on the theoretical part of the subject in such a form that it could be applied in practice.

According to the theory of thermo-dynamics, there was a point so low in the thermometric scale that all heat was there considered to be absent. This point was reached 461° below the zero of Fahrenheit's scale; and temperatures measured from this real zero were called absolute temperatures. It followed that the absolute temperature of any substance was its temperature as measured by Fahrenheit's thermometer plus 461°.

This being understood, let the absolute maximum temperature of the air in the hot or compression end of the cooling machine be expressed by τ_1

The absolute minimum temperature of the air in the cold or expansion end of the machine be expressed by τ

Also let it be supposed that the machine was theoretically perfect, that it worked without mechanical friction, that it neither received heat from nor radiated heat to surrounding objects, and that it conducted no heat through its own substance from the hot to the cold end.

On this supposition let the cooling work done, expressed in pounds of water cooled 1° Fahrenheit (the British thermal unit), be denoted by . . . C

Let the power (expressed in foot lbs.) required to do the cooling work C, by the supposed perfect machine, be denoted by . . . . . P

Then, by the received principles of thermo-dynamics,

$$P = 772\ C \times \frac{\tau_1 - \tau}{\tau} \quad . \quad . \quad . \quad . \quad . \quad . \quad A$$

or conversely,

$$C = \frac{P}{772} \times \frac{\tau}{\tau_1 - \tau} \quad . \quad . \quad . \quad . \quad . \quad . \quad B$$

The power by these formulæ for any given cooling work was, of course, smaller than could be attained in practice; but they, nevertheless, were useful in showing the limit short of which all practical efforts must stop, and they afforded a useful means of estimating the degree of efficiency which any given machine had attained. It was desirable to notice the important bearing that the quantity $\tau_1 - \tau$ had in determining the power which, it would be observed, increased in either the same or a more rapid ratio, than this difference between the temperature of the two ends of the machine.

The improvement which Mr. Kirk had made in the new wet air as compared with the original dry-air machine was thus readily understood. Dry air was a very bad conductor of heat, and to enable the necessary amount of heat to be transmitted through the iron plates from the air to the water, or *vice versâ*, required that the air at the hot end should be much hotter than the water that carried off the waste heat; and that the air at the cold end should be much colder than the water or brine that was being cooled. The difference of temperature between the air at the two ends of the machine ($\tau_1 - \tau$) was thus much greater than if there had been an easier transfer of heat between the air and water. Mr. Thomson thought, from experiments he had made, that this difference of temperature must be considerably more than Mr. Kirk supposed. The formula A showed that this must cause a great addition to the power required to work the machine; and that the wet-air machine, where the air and water came into intimate contact with each other, must, by diminishing the difference of temperature between them, be able to work with less power. The trials of the machines described in the Paper proved that this was the practical result to a great extent.

One of the most characteristic peculiarities of Mr. Kirk's cooling machines was the use of what were termed "regenerators"—a

name derived from Stirling, who was the original inventor of them, as applied to his hot-air engine. The object and effect of these appendages had sometimes been misunderstood. Theoretically, a machine constructed to work without them ought to be as efficient as one made to work with them. But the regenerators gave these great practical advantages: they enabled the cooling effect of each stroke of the machine to commence at the point where the last left off; that was, if one stroke cooled the air 10°, the next stroke might cool it an additional 10°, and so on, and thus admit of the temperature of the air being lowered to any required degree without the excessive variations of pressure that would otherwise be required. By their means also the machine was enabled to work constantly with the same air, which could therefore without practical difficulty be of any desired density; and this, as had been remarked, was an important point. That the conclusion derived from the original experiments was correct, to the effect that the system of regenerators was the most likely to yield good practical results, was proved by the fact, that since then two persevering attempts on a large scale, with an expenditure of ample means, had been made, by Mignot and by Windhausen, to compete with Kirk's machines by means of air machines without regenerators; but both had failed to obtain equally good results.

For the sake of simplicity, the formulæ A and B had been spoken of as applying to air machines only; but by the received principles of thermo-dynamics it was readily proved that they applied equally to all cooling machines, no matter whether they operated by means of air, ether, ammonia, or any other fluid. In so applying them, it was to be understood that τ_1 and τ were the highest and the lowest absolute temperatures of the working fluid at the hot and the cold ends of the respective machines. Also, in the ammonia machine, or others working on the same principle, it was to be observed that no mechanical power being applied, P must be understood to denote the amount of heat that was theoretically required at the rate of 1 heat unit to 772 foot lbs. of power. In other words, the formula A for an ammonia machine would become—heat required to do the work $C = C \frac{\tau_1 - \tau}{\tau}$. The relative merits of cooling machines made on the different systems that had been described could not therefore be determined by purely theoretical considerations, from which point of view all were equal.

The principal defect of the air machines, besides the bad con-

ducting power of air, and its effects as already described, was due to the circumstance that the comparatively small theoretical power required to do the work was the excess of the power required to compress the air beyond that given out during its expansion; and both of these were large compared with their difference, as was shown in the Paper. This necessitated the strength and working friction of the machine being such as were due to two powerful engines working against each other, in order to utilise a comparatively small difference of power. In this respect the ether machines had so great an advantage that it was not probable that air machines could successfully compete with them where economy of power alone was considered.

The ammonia machines had, theoretically, a great economical superiority, in heat being so much cheaper than its equivalent of mechanical power; but the practical difficulties involved in their use were so great, that he had not been able to learn that such machines had yet been made to work efficiently and regularly for considerable periods.[1] There was this difficulty attending

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[1] If P is taken as equal to 1 HP. working one minute, or 33,000 lbs. raised 1 foot high,

$$C = \frac{33{,}000}{772} \times \frac{\tau}{\tau_1 - \tau} = 42{\cdot}733 \frac{\tau}{\tau_1 - \tau}.$$

This form of the formula was a convenient one for testing the efficiency of the different machines, whose performance had been referred to in the Paper or in the Discussion. In applying it to this purpose it is to be observed that, if a cooling machine were perfect, the temperature of the working fluid would be the same as that of the water passing from the hot and cold ends of the machine. This of course could never be the case in practice, but to whatever extent the actual temperatures of the working fluid were different from those of the water it acts on, to the same degree this constituted an imperfection in the machine; and therefore, in measuring its efficiency as compared with a perfect machine, the maximum and minimum temperatures of the working fluid (τ_1 and τ in the formulæ) should be taken as the same with those of the water or brine passing from the hot and cold ends of the machine.

This had been done in the following examples; and the specific heat of brine per gallon had been taken as 11 instead of 10 for pure water. Probably the specific heat of brine was hardly so high, but the difference could be of no practical importance in these examples.

Mr. Kirk's trial of the dry-air machine at the Bathgate Works:

Here

$$\tau_1 = 94 + 461 = 555$$
$$\tau = 23{\cdot}5 + 461 = 484{\cdot}5$$
$$\tau_1 - \tau = 60{\cdot}5$$
$$\frac{\tau}{\tau_1 - \tau} = \frac{484{\cdot}5}{60{\cdot}5} = 8{\cdot}0$$
$$C = 6{\cdot}7 \times 11 \times 8{\cdot}5 = 626{\cdot}45 \text{ heat units.}$$
$$P = 23 \text{ Indicated HP.}$$

[Therefore

the use of ammonia, that, for this climate, it required for making ice to work with a pressure of 160 to 170 lbs. on the square inch, and in hot countries 200 lbs., and with machines working at those high pressures it was almost impossible to keep them absolutely tight.

Therefore the cooling effect produced per horse-power per minute

$$= \frac{626{\cdot}45}{23} = 27{\cdot}2 \text{ heat units,}$$

and the cooling effect that would have been produced by a perfect machine per horse-power per minute

$$= 42{\cdot}733 \times 8 = 342 \text{ heat units.}$$

The efficiency of the machine was therefore $= \frac{27{\cdot}2}{342} = {\cdot}08$,

that of a perfect machine being 1.

Mr. Kirk's five hours' trial of the wet-air machine at the maker's works:

Here

$$\begin{aligned} \tau_1 &= 81 + 461 = 542 \\ \tau &= 47{\cdot}25 + 461 = 508{\cdot}25 \\ \tau_1 - \tau &= 33{\cdot}75 \\ \frac{\tau}{\tau_1 - \tau} &= \frac{508{\cdot}25}{33{\cdot}75} = 15 \end{aligned}$$

$C = 20{\cdot}6 \times 10 \times 14 = 2884.$

$P = 37$ Indicated HP.

Therefore the cooling effect produced per horse-power per minute

$$= \frac{2884}{37} = 78 \text{ heat units,}$$

and the cooling effect that would have been produced by a perfect machine per horse-power per minute

$$= 42{\cdot}733 \times 15 = 640.$$

The efficiency of the machine was therefore $= \frac{78}{640} = {\cdot}12$,

that of a perfect machine being 1.

Mr. Kirk's trial of the wet-air machine (the same as in the last trial) in ordinary work at the Oakbank Works:

Here

$$\begin{aligned} \tau_1 &= 73 + 461 = 534 \\ \tau &= 28{\cdot}25 + 461 = 489{\cdot}25 \\ \tau_1 - \tau &= 44{\cdot}75 \\ \frac{\tau}{\tau_1 - \tau} &= \frac{489{\cdot}25}{44{\cdot}75} = 11 \end{aligned}$$

$C = 13{\cdot}05 \times 11 \times 8\frac{3}{4} = 1256$ heat units.

$P = 25$ indicated HP.

Therefore the cooling effect produced per horse-power per minute

$$= \frac{1256}{25} = 50 \text{ heat units,}$$

and the cooling effect that would have been produced by a perfect machine per horse-power per minute $= 42{\cdot}733 \times 11 = 470$ heat units. [The

An engineer accustomed to steam engines working at equally high pressures might naturally suppose that that pressure was nothing to speak of; but it should be borne in mind that an amount of leakage, that, in an ordinary steam engine would be thought nothing of, would be absolutely fatal to an ammonia machine, owing to the poisonous character of the ammonia, and the expense and trouble of renewal. The great thing was to have a machine that would work continuously, and tnat, as far as he had been able to ascertain, was not the case with ammonia machines. The ether machines described by Mr. Siddeley were erected under contract by the firm with which he was connected, and he was able to confirm from personal observation the figures which Mr. Siddeley had quoted as showing the results of their working. There need be no further doubt upon the subject, as he was authorized to say by the kindness of Mr. Wilson, the chief brewer at Messrs. Coombe's, that any member of the Institution, or any gentleman feeling an interest in the subject, would be permitted to test the machines in any way they chose, if they did not interrupt the regular work of the brewery; and for this purpose a Richard's indicator, thermometers, &c., would be provided.

The efficiency of the machine was therefore $= \frac{50}{470} = \cdot 1$,

that of a perfect machine being 1.

Trial of an ether cooling machine at Combe's Brewery, as given by Mr. Siddeley:

Here

$$\begin{aligned} \tau_1 &= 83 + 461 = 544 \\ \tau &= 47\tfrac{1}{2} + 461 = 508\tfrac{1}{2} \\ \tau_1 - \tau &= 36\tfrac{1}{2} \\ \frac{\tau}{\tau_1 - \tau} &= \frac{508 \cdot 5}{36 \cdot 5} = 14. \end{aligned}$$

165 barrels per hour is equal to

$$\frac{165 \times 36}{60} = 99 \text{ gallons per minute,}$$

and

$$C = 99 \times 10 \times 7\tfrac{1}{2} = 7425 \text{ heat units.}$$
$$P = 30 \text{ indicated HP.}$$

Therefore the cooling effect produced per horse-power per minute

$$= \frac{7425}{30} = 247 \cdot 5 \text{ heat units,}$$

and the cooling effect that would have been produced by a perfect machine per horse-power per minute $= 42 \cdot 733 \times 14 = 598$ heat units.

The efficiency of the machine was therefore $= \frac{247 \cdot 5}{598} = \cdot 4$,

that of a perfect machine being 1.

In answer to a question as to the cost of production by the respective machines,—

Mr. Reece stated that by his machine the cost of cooling a barrel of water through 20° was 1*s.* per 1,000 gallons, and the cost of making a ton of ice, taking coal at 30*s.* a ton, was exactly 5*s.* It was, he said, new to him to learn that ammonia machines were worked with 180 or 200 lbs. pressure. Ammonia condensed into a liquid perfectly at a temperature of 68°, and with a pressure of 120 lbs. A machine had been running day and night for four months without stopping, except for two hours once a week to change the liquor, and he had never discovered the large losses to which reference had been made.

Mr. Siddeley said that the cost of production by his machine was from 15*s.* to 20*s.* a ton, which included every item of expenditure, interest on capital, rent, &c.; but if the mere fuel and labour expended in the production were taken, the cost would only be from 8*s.* to 14*s.* per ton, according to the size of machine. With water-power the cost would be from 7*s.* to 10*s.*, as had been practically demonstrated at Penzance. With regard to the ammonia machine, he had certainly seen one at work at a pressure of 170 lbs.

Mr. H. J. West said the cost of making transparent ice by his machine was 12*s.* per ton, and opaque ice from 7*s.* to 8*s.* per ton. With large apparatus, say equal to a turn out of 50 tons daily, the cost in both cases would be less.

Mr. Siemens explained that he had no desire to disparage Mr. Kirk's ingenious contrivance—on the contrary, he wished it every success—but he could not help observing upon the drawbacks which he conceived were incidental to the construction of the machines. He admitted that the construction had the advantage of giving a greater amount of power in a limited space than the Windhausen machine, but, as a set off, the greater back pressure or lost effect incidental to the engine must be taken into account. Other speakers had alluded to the thermo-dynamic theory, and had argued that, inasmuch as a unit of heat could only develop 772 units of force, so 772 units of force were necessary to abstract one unit of heat in the production of ice. If the object was to create a unit of heat, he could agree with these remarks, but refrigeration meant only the displacement of heat from one temperature to another, and involved the amount of force necessarily due to that step. In starting from the absolute zero point, water of the ordinary temperature of 60° was in reality just about 500° hot; and in depressing this temperature to 10°, work had

to be accomplished amounting to $\frac{60}{500}$, or but little more than $\frac{1}{10}$th of the mechanical equivalent of the heat so transferred. This proposition could be verified by means of two diagrams, one representing the curve of air compression with simultaneous injection of cold water, and the other the air expansion after cooling; the difference of magnitude between the two was only $\frac{1}{10}$th of the air compression diagram, and $\frac{1}{9}$th of the air expansion diagram, which latter represented the work of refrigeration which was accomplished. This result followed generally from the formula by Clausius just submitted by Mr. Thomson.

Mr. SIDDELEY remarked that Mr. Kirk's machine did its work well, and he believed it to be the best of its kind, notwithstanding what had been said in favour of Windhausen's machine. Nevertheless, he could still show a decided superiority in favour of the ether process; and in support of this assertion he would give a few particulars of work done. In the summer of 1872 a machine was erected at Messrs. Combe's brewery, Long Acre, for cooling the water used for refrigerating the wort. The water was delivered by the well-pumps to the refrigerator of the machine, where it was cooled, and, by means of a pump attached to the apparatus, was forced through the wort refrigerators up to the tank at the top of the brewery, this tank being about 80 feet above the level of the machine. The water was passed through the machine at the rate of 165 barrels, or 5,940 gallons per hour, and was cooled from 55° to $47\frac{1}{2}° = 7\frac{1}{2}°$. The indicated HP. expended in performing this work was $29\frac{1}{4}$ HP. with the water-pump standing, and $34\frac{1}{2}$ HP. with the pumps working; but as the pumping did not strictly belong to the cooling part of the machine, and in this instance was in excess of what was usually required, the first must be taken as the power exerted, in comparing this machine with others. Before entering into this comparison, he would briefly show the advantage of this mode of cooling over the use of ice dissolved in water, or otherwise applied. The heat taken out of the water in passing through the machine, calculated in gallons cooled 1°, was—

$$165 \text{ barrels} \times 36 \text{ gallons} \times 7\tfrac{1}{2}° = 44{,}532 \text{ gallons.}$$

This brought into heat units, was

$$44{,}532 \text{ gallons} \times 10 \text{ lbs.} = 445{,}320 \text{ heat units,}$$

and this $445{,}320 \times 24 = 10{,}687{,}680$ heat units abstracted from the water in twenty-four hours.

In a Paper on Artificial Freezing and Refrigeration,[1] Dr. Paul

[1] *Vide* "Journal of the Society of Arts," December 18th, 1868.

had stated that "the total quantity of heat to be abstracted from water at 60°, in order to produce one ton of ice, is 382,256 heat units." Therefore the heat units abstracted by the machine, divided by this sum, would give the number of tons of ice which, by melting, would be requisite to produce in twenty-four hours the same amount of cooling. This was nearly 28 tons, and it was produced with an expenditure of about one-fourth the power required to make that quantity of ice, while the cooling was more rapidly and efficiently performed. In connection with this subject, he would direct attention to an arrangement adopted by Mr. Wilson, of Messrs. Combe and Co., by which the exhaust steam from the engine of the machine was employed to heat the water used in brewing, say about 1,200 barrels per day, and thus the actual cost of cooling the water for refrigerating was reduced to a minimum. A second machine of the same size was started during the last season, and the results were equally satisfactory, as also were those from a similar machine erected at Messrs. Bass and Co.'s brewery at Burton-on-Trent. In comparing the performance of this machine with Mr. Kirk's, he thought the fairest way would be to reduce the work done to the number of heat units taken out of the water per HP. per minute; the result was—

	Siddeley and Mackay's Ether Machine.	Kirk's Wet Air Machine.
HP. spent in driving	30	37
Quantity of water cooled per minute . .	100 gallons.	21 gallons.
Temperature of Inflow	55°	61·25°
,, of Outflow	47·50°	47·25°
Heat Units taken out of the water per HP. per minute	250	80

or fully three times the amount of work done per HP.

From data obtained from machines employed in ice-making in Glasgow, he was able to make a more complete comparison, and further to show the superiority of the ether machines. These machines were each capable of producing 5 tons of ice per twenty-four hours, and this was done with an expenditure of 20 indicated HP. Their performance might be compared with the dry-air machine, with the following results:—

ICE-MAKING TEMPERATURES.

	Siddeley and Mackay's Ether Machines.	Kirk's Dry Air Machine.
HP. spent in driving	20	23
Quantity of brine cooled per minute . .	32 gallons.	6·7 gallons.
Temperature of Inflow	32°	32°
,, of Outflow	23°	23·5°
Heat Units abstracted per HP. per minute	144	24·3

or nearly six times the quantity of cooling.

COOLING WATER TEMPERATURES.

	Ether Machine.	Wet Air Machine.
HP. spent in driving	23	37
Quantity of fresh water cooled per minute	35 gallons.	21 gallons.
Temperature of Inflow	60°	61·25°
,, of Outflow	45°	47·25°
Heat Units abstracted per HP. per minute	230	80

Compared with the wet-air machine cooling at lower temperatures, the proportions would be thus:—

	Ether Machine.	Wet Air Machine.
HP. spent in driving	20	25
Quantity of water cooled per minute . .	40 gallons.	13 gallons.
Temperature of Inflow	37°	37°
,, of Outflow	28°	28°
Heat Units taken out of water per HP. per minute	144	47

In these two cases the results were in favour of the other machines in the proportion of three to one. The amount of cooling water required would also make this comparison still more favourable, as the proportion of this would be from a third to one-half the quantity. With reference to Windhausen's machine, it must have been greatly improved since one was exhibited in London, if it would produce ice at anything like the rate stated. At that time he was informed it would make 3 tons of ice per twenty-four hours, or cool 300 gallons of water from 65° to 40° = 25° per hour; but the power required was considerable, which he estimated at from 25 to 30 nominal HP. There was certainly great room for improvement, and he could not conceive how ice could be made so cheaply with it as stated.

Referring to the last machine introduced for producing cold, Mr. Reece's ammonia machine, it did not appear able to work in a satisfactory or reliable manner, from what causes he was not prepared to say. It was almost impossible to compare it with

the ether machine. It had been stated that ice could be made for less than 5*s.* per ton; but there was an important omission in that estimate. The cost of producing 50 tons of ice was given, and the water to form the ice was taken into account, but not the cost of water for condensing; and, as the quantity required for this purpose was large, he estimated that this would at least treble the cost of the ice, and raise it to 15*s.* or 20*s.* per ton. For cooling purposes it was apparently a failure. He had just completed the erection of an ether machine to supersede an ammonia machine, which would not perform the work guaranteed by more than one-half, and which was extravagant in cooling water, besides being dangerous from the excessive pressure carried in parts of the machine, and the difficulty experienced in keeping it tight.

Mr. Kirk, in reply, said he assented to the remark, that the efficiency of an air machine became less as the temperature of absorbing heat was lowered, but this was not confined to an air machine. It was a necessary condition of a heat engine, whatever the nature of the medium employed, that the quantity of heat absorbed at any temperature by expansion was in proportion to that temperature expressed in the absolute scale. The same was true of the heat given out by compression. Thus, in a heat engine, containing say 1 lb. of air, for a given difference of temperature between that of receiving and rejecting heat, the power would be the same, at whatever part of the thermometric scale these operations took place; but the actual quantity of heat absorbed and rejected diminished as lower temperatures were employed. Thus, the highest temperature of cooling was in practice about 45° Fahr. (506°), and the lowest about 15° Fahr. (476°); and if in both cases the temperature of rejection of heat was taken at 75° Fahr. the power required would be, while cooling at 15°, double that required while cooling at 45°, and the heat absorbed or cooling done by the same weight of fluid about 6 per cent. less. The determination of the respective merits of various kinds of machines under different conditions of temperature could not be thus ascertained. In comparing air and ether machines he differed from Mr. Siemens, and maintained that the air machine was working to the best advantage when the difference between the temperatures of absorbing and rejecting heat was large, and the ether machine when that difference was small. In the air machine, when the difference of temperatures was small, the low power which ought to be required to drive the machine, being the difference between the work of compression and of expansion, bore but a low ratio to

the whole power transmitted through the moving parts of the machine which was the sum of these. Since the loss of power by mechanical friction was that due to the sum of these powers, when the difference of temperature was small this bore a high ratio to the useful work; as the temperature at which expansion took place was lowered, the total friction was slightly diminished, and the ratio of useful work to friction rapidly increased.

In the ether machine compression by external work was to a great extent replaced by condensation, or internal work unaccompanied by friction. In this machine, as a low temperature of evaporation—absorption of heat—was reached, mechanical difficulties rapidly increased, a high vacuum must be maintained, unavoidably accompanied by increased leakage of air; and although means were provided for removing this air from time to time, it could not be done without a loss of some of the most volatile part of the ether, and a reduction in the efficiency of the machine. On the other hand, if a high temperature of condensation could not be avoided, a pressure in the pump and condenser considerably above the atmosphere must be employed, attended also by a loss, through leakage, of the volatile ether. In addition to these difficulties the ether was gradually deteriorated by the oil used at the stuffing-boxes, and in the cylinder of the pump, and the higher the vacuum required the more rapidly did this take place. Not only did the gradual deterioration of the volatile quality of the ether go on more rapidly at low temperatures than at high, but at low temperatures it had a much more prejudicial effect. Thus the ether machine at Bathgate, while working at about 15° Fahr., would frequently from these causes have its efficiency reduced one-half.

In his remarks on the unmanageable bulk of air machines, whether motive power engines or refrigerating machines, Mr. Siemens seemed to have overlooked the fact that in Stirling's engine, and in the machines described, the air was much above atmospheric density. As a matter of fact, in Stirling's engine the mean effective pressure on the piston was fully 37 lbs. per square inch, quite 50 per cent. higher than in the best modern steam engines, and the size of cylinder required in the air engine was proportionately less. Similarly, the air machine was less in bulk than the corresponding ether machine. He considered the application of a regenerator in Stirling's engine, and the whole arrangement of the engine, one of the greatest steps made in scientific engineering in the present century. It was an error to suppose that the utmost possible efficiency of the air in this engine was $\frac{1}{6}$th. Reference to the full analysis of the performance of this engine, by the late

Professor Rankine,[1] would show that the efficiency of the air was $\frac{3}{10}$, fully 50 per cent. more than that of steam in the best steam engines. Besides, so far as he was aware, it was the only air engine which, notwithstanding some failures in the heating vessels, had stood the test of working a factory for some years. The superiority of this engine to Ericsson's was obvious; and in adopting an inversion of it in preference to Ericsson's, which he had tried, he considered he had acted wisely.

In a large moist-air machine recently sent abroad, he expected that the coal required would not exceed 4 cwt. per ton of ice.

In reply to Mr. West, as to his motive in bringing out an air machine, after using for some time an ether engine, and as to the possibility of risk from fire attending the use of ether being imaginary, he would record the accident which induced Messrs. Young and Meldrum to dispense, if possible, with its use, and to incur the expense of a long and costly series of experiments to find a substitute. There had from the beginning been frequent interruptions to the work, arising from imperfections in the ether boiler and breakage of valve spindles; but the accident which alarmed the firm was the collapse and fracture of the shell of the ether boiler without warning, during the busiest part of the season. Though every precaution was taken, the only light being a lamp near the door, the heavy ether vapour spread insidiously over the floor, till, reaching the lamp, which was near the ground, it caught fire and covered the whole floor with a carpet of flame. The sight was magnificent while it lasted, which was only for a few moments, and fortunately happening while men were present, the fire was extinguished without damage.

As to the large quantity of cooling water used in the experiments, he would explain that the experiments simply afforded the means of ascertaining the units of rejected heat, which might be made up of more heat and less water, or of less heat and more water. In regard to the comparison made by Mr. Siddeley between the performances of air and ether machines, it must be understood that both the dry-air machine and the wet-air machine quoted were the first of their class, and not the most improved; but they were the only ones of which he could furnish complete results of both absorbed and rejected heat and power, ascertained by continuously repeated measurements and corresponding diagrams. Those who knew the difficulty in getting experiments made with machines

[1] *Vide* "A Manual of the Steam Engine and other Prime Movers," p. 362.

constantly at work in manufactories, and the time they took, would excuse his not being able to quote more recent performances.

Although the machines of the Glasgow Ice Company, referred to by Mr. Siddeley, were the best specimens of ether machines, and had worked well, the results quoted had not been by any means regularly maintained, owing chiefly to the causes mentioned, and the consumption of ether had been considerable. Besides, a single experiment at 23° was not a fair test of the power required in making marketable ice, the temperature being for a great part of the time below this. As to the coal used by the machine at Bathgate, he ought to explain that a short egg-ended boiler was used, and that the coal from neighbouring pits was bad and cheap.

The dry-air machine employed in ice-making in China was reported by Mr. Kyle as having required 15 cwt. of Formosa coal per ton of ice made; in this case, also, the steam-boiler was of an inefficient type.

Professor C. Piazzi Smyth stated, through the Secretary, that the subject of the mechanical production of cold had been much prosecuted by him from 1846 to 1856, with more or less countenance and assistance on different occasions from Mr. James Stirling, Mr. William Petrie, and the late Professor Macquorn Rankine. The special application which he had in view was the cooling of air in rooms, particularly of hospitals in tropical climates, where he had seen something of the waste of European life and energy, which was ever going on there so fearfully though silently, and mainly for want of some domestic application the converse of a fire and a fire-place.

After carrying on some experiments, on a small scale only, Mr. James Stirling kindly favoured him with large engineering drawings of a power-driven air-pump, and a convenient system of self-acting coolers for the hot air of compression. Mr. William Petrie supplied several papers on the methods of escape to be furnished to the cooled air of compression, to prevent its reheating itself in the act of escape. Finally, when Government allowed, towards the end of the Crimean war, a small sum for constructing a cheap model of an air-cooling machine, to be worked only by hand, Professor Macquorn Rankine furnished the design for it, bore part in all the trials with it, and prepared the final report to Government when the apparatus was sent to Chatham in 1856.

The general principle proceeded on was, to pump air under compression into a worm still; to take the heat of compression out of

it there by conduction through the pipe; to utilize the force of the compressed air, or make it do work in escaping, and then let the cooled and expanded air pass on to the apartments to be cooled. The whole circle of the operations was therefore entirely mechanical; and although in 1852 it had had to compete at the British Association, in description, with what was urged by Mr. William Sykes Ward, of Leeds, and others, in favour of the introduction of physical and chemical forces also—as the employment of sulphuric ether, and continued supplies of freezing salts—both Professor Rankine and he persisted in abiding by the purely mechanical method of acting on air, as being that which would sooner or later become the most sufficient method for the constant work of the future. But neither were altogether content with the results of the large wooden model in 1855–6. To save power, when that had been ordered to be confined to the human hand, Professor Rankine had given the machine the so-called frictionless plungers working in vertical troughs of water; the amount of compression of air thereby possible was a very small part of only one atmosphere. The cooling result expected to be gained had been calculated on closely, and was found, in practice, to be generally almost entirely overborne by the effects of watery vapour.

Yet there was another drawback to the practical success, which was not suggested till 1861. Having heard that Mr. Kirk had adopted for his air-cooling machine the converse, not of the steam-engine, but of Stirling's air-engine, he remembered not only certain advantages in the movement of the regenerator of that engine, acting in place of slide-valves, and in the facilities for keeping watery vapour out of the interior of the machine, and all that it had necessarily to act upon, but also Mr. James Stirling's own emphatic account years before, touching his greatest discovery in working his brother's air-engine as a power-engine, viz., that though everything else might be admirable in its own way, no paying results could be got out of the machine, as a whole, when dealing with air of one atmosphere of pressure only. That the results improved continually as the circulating medium was made more dense, until at ten and twelve atmospheres one horse-power per hour could be got with 3 lbs. to 4 lbs. of coal. This approached the economy of a good steam-engine, and surpassed the results of many. From that moment he perceived Mr. Kirk had got hold of the right idea; and his practical skill in working it out had been admirable. The scientific problem of air-cooling at least was now solved; there was no longer any mystery, any uncertainty, any difficulty, wherever any customer chose to pay for it. For

several years past he had recommended all private applicants from India to consult Mr. Kirk; and he was persuaded that, if Her Majesty's Government really desired to have the first element of health for their troops in the tropics—viz., coolness—introduced into the hospitals of both the East and West Indies, it must be by the air-cooling machine.

Mr. John D. Barry furnished, through the Secretary, the following description of Mr. A. H. Tait's compound pneumatic ice apparatus. This process differed materially from those hitherto introduced, avoiding the objectionable use of the chloride of lime, or brine bath; and, where pure water was frozen, furnishing clear ice, in blocks of any thickness required, at a cost not exceeding 8*s.* to 10*s.* per ton, according to the price of coal and labour. The first outlay was less than that for any apparatus yet in the market for the same quantity of ice produced, and the ice was pure, clear, and wholesome. The apparatus consisted of two sets of pumps driven by steam or water power; one set, No. 1, to compress sulphurous acid gas into fluid at a pressure of about 45 lbs. per square inch, or four atmospheres; and the other, No. 2, to compress atmospheric air at a pressure of about 75 lbs. per square inch. To these were added two cylinders furnished inside with pipes, likewise designated Nos. 1 and 2, and an ice box, in which the water to be frozen was congealed by a constant current of cold air, that passed under and over the surface of the water in the vessel placed in the ice box. Sulphurous acid, which was necessary, might be made pure, and economically, by forcing the products of the combustion of sulphur in a suitable furnace into an open vessel containing milk of lime or caustic soda, where the sulphurous acid was retained in the form of sulphite of lime or soda, and the nitrogen, carbonic acid, and undecomposed atmospheric air passed off. The sulphite of lime in its fluid state was then placed in another air-tight wooden vessel, furnished with a vessel at the top to contain sulphuric acid, which was let down as required into the fluid sulphite of lime, in order to set free the sulphurous acid, which should be passed through a close vessel lined with lead, containing sulphuric acid of 66° Beaumé, so as to deprive the sulphurous acid of vapour of water, which was detrimental in the process. Sulphurous acid might also be made in various other ways, viz., by sulphuric acid and scrap copper, sulphuric acid and charcoal, sulphur and sulphate of iron, with pyrites, etc.; but he preferred the combustion process. The sulphurous acid gas set free by the action of the sulphuric acid on the sulphite of lime now passed to the pumps or compressors

No. 1, by which it was forced into an upright cylinder filled with tubes of copper wiped outside with a composition of lead and tin, the inside of the cylinder being lined with sheet lead. Into this cylinder outside of the pipes the gas was forced by the pumps No. 1, and was condensed at a pressure of about 45 lbs. per square inch, aided by a constant stream of cold water which surrounded the cylinder, and also passed through the pipes inside, in order to reduce the gas under compression to the temperature of the water used in cooling. This condensed gas was now let into another cylinder, No. 2, lined with lead inside, and filled with copper pipes, the flow being regulated so as to keep up the pressure in the cylinder No. 1. The copper pipes in No. 2 were also wiped outside with a composition of lead and tin, the gas expanded in this cylinder outside pipes, and after its expansion was again returned to the pumps or compressor No. 1 to be again liquefied and expanded. The compression of the gas in one cylinder and its expansion in the other was therefore continuous, and there was no waste of gas if there were no leaks in the machinery. Liquid sulphurous acid at a temperature of 60° Fahrenheit boiled at 14° Fahrenheit, or 18° below the freezing point of water under ordinary atmospheric pressure; and if allowed to assume the form of gas freely, it converted the fluid left behind into a solid, so great was the reduction of temperature. He was not aware of any reliable data about the latent heat of evaporation of fluid sulphurous acid, but from the general fact that the latent heat was inversely as the specific gravity of vapours at their boiling point, he estimated the latent heat of sulphurous acid at 966, equal to 214 units of heat. This capacity, coupled with its low boiling point, and the moderate degree of pressure requisite to convert it into fluid, made this gas the most valuable agent for the manufacture of ice in the whole range of chemistry. To compress 1,000 cubic feet of sulphurous acid gas into fluid, and to discharge the same into gas at 45 lbs. per square inch above atmospheric pressure, would require a power equal to about 3,700,000 foot pounds; or, taking the efficacy of the machine at only 50 per cent., 7,400,000 foot pounds would be required to compress 1,000 cubic feet of gas into 171 lbs. of fluid acid, or it would require nearly 6 cubic feet of gas. One HP. would furnish 0·76 lb. of fluid acid per minute, equal to 456 lbs. in ten hours. One pound of water at 62° Fahrenheit must have 174 units of heat abstracted to form ice at 32° Fahrenheit, taking into consideration unavoidable losses. One pound of liquid sulphurous acid would, by its evaporation, convert 1 lb. of water into ice with 1 HP., equal to 456 lbs. of ice in ten hours. To make 1 ton of ice

in ten hours would require 5 HP., consuming not more than 350 lbs. of coal, or, in other words, in practical work 1 ton of coal would produce from 6 tons to 7 tons of ice.

Mr. Bourne observed that it would be an invidious task to pronounce upon the rival pretensions of the different freezing machines of which the characteristic features had been expounded; but it might not be inopportune to offer a few general remarks on the subject of refrigeration.

Cold was produced by radiation into space, by the liquefaction of solids, by the vaporisation of liquids, by the dilatation of gases, and by electricity.

In the upper provinces of India ice was obtained by exposing water, in shallow porous vessels, to the cooling influence of the sky during clear nights. The evaporation from the porous vessels cooled down the water, and the radiation of heat from the surface produced a film of ice, which in the morning was skimmed off and preserved for use. It was a necessary precaution to place the vessels upon a layer of straw, so that they might not be affected by radiation or conduction upward from the earth; and it was also indispensable that the sky should be free from clouds, else the heat was radiated back from the clouds, and freezing did not take place. The operation of the same laws occurred in the deposition of dew. The surface of the earth was cooled by radiation, and the moisture of the air was condensed by the cold surface and precipitated as dew, in the same way in which moisture was precipitated upon the surface of a glass of cold water in summer, or upon the windows of a heated room when the air outside was cold.

If ice at 32° was heated over a fire, it would take some time to melt, although it had all the while been receiving heat, and although the resulting water was still only at a temperature of 32°. This showed that melting absorbed heat; and when the heat was supplied from any extraneous source the liquefaction was a source of cold. Thus, when certain salts were melted in water cold was produced, and those salts were called freezing mixtures. So also a low temperature resulted when snow and salt were melted by being mixed together.

The vaporisation of liquids was one of the usual ways of producing cold. In India water was cooled by pouring it into a metal bottle, which was then wrapped in a wet cloth and swung in the sun. The heat and current of air induced rapid evaporation, which cooled the contained water. When the hot winds prevailed in the arid parts of India, houses were cooled by blowing air

through a thick matting kept constantly wetted with water. The evaporation of the water cooled down the air to an agreeable temperature, and the hotter the wind the greater was its avidity for moisture, and the greater the refrigeration.

The dilatation of gas, as well as the vaporisation of liquids, afforded a powerful refrigerating agent, and one or both of these expedients was called into play in the different freezing machines. In Mr. Kirk's machine atmospheric air was the gas employed. The air was compressed by a piston, by which means the temperature was raised, as in the syringe for lighting amadou tinder by the sudden compression of air. The heated air was cooled by water, and was then suffered to expand, when it sought to recover from surrounding objects the heat it had lost, and thus lowered their temperature.

Electricity was a source of cold not yet developed, but which appeared worthy of attention. More than thirty years ago Peltier, in experimenting on the thermo-electric battery, discovered that cold was produced by a current passing from the bismuth to the antimony. All the freezing machines described in the course of the discussion were virtually thermo-dynamic engines inverted. Such engines uniformly worked with a great loss of effect; and the efficiency of electro-magnetic engines was about four times greater than that of heat engines. A similar relation might, perhaps, hold in the inverted machines.

In all thermo-dynamic machines there must be two temperatures, just as in the generation of power by gravity there must be two levels, and in the subsidence of the weight from the higher to the lower level power was generated. In freezing machines there was only one temperature to begin with, and that had to be raised at one end of the machine, or to be depressed at the other end, by an expenditure of power, just as power had to be expended in winding up a weight. It was a law of thermo-dynamics, that the same quantity of heat, with the same extremes of temperature, would generate the same amount of power, whatever might be the medium through which the heat was made to operate—whether it was steam, or air, or water, or metal, or any other substance. The converse of this proposition would also be true; and just as a given expenditure of heat would produce a corresponding amount of power, so would a given expenditure of power produce a corresponding amount of refrigeration. Excluding details, therefore, and without entering into minutiæ, there was no theoretical reason why one freezing machine should not be as efficacious as another. The difference between them was not so much a differ-

ence in principle as a difference in cost, or convenience, or safety, or something of that nature. As heretofore constructed, the air-machine appeared to absorb more power to do the same work than some others; but this result he considered accidental to the mode of construction adopted, and that it might be obviated in future examples. If, in point of cost, all the systems were made equal—which he believed to be the inevitable tendency—then the question of comparative merit would narrow itself to considerations of safety and convenience. He could not assent to the remarks of one of the constructors of ether machines, as to the visionary nature of the apprehensions entertained in regard to the dangers of ether, especially on board ship. A system of supplementing the power of steamers by the employment of ether was, some years ago, proposed by M. Du Trembley, and this system was applied to several steamers by the late Mr. J. W. Jameson, Assoc. Inst. C.E., who had read a Paper on the subject before this Institution, and who had referred to some of the accidents that had occurred.[1] He did not maintain that the risks of using ether in freezing machines on shore were as great as those arising from its use in engine-rooms at sea; but he thought that all vapours, like those of ether or ammonia, which were inflammable or poisonous, and liable to leakage under high pressures, were objectionable on shipboard, whereas atmospheric air was harmless. He believed, too, it was on board ship that one of the most valuable applications of the freezing machine would yet be found—in enabling frozen meat to be brought from all parts of the world in vessels specially constructed for its conveyance.

Mr. Greaves observed, through the Secretary, that the study of this subject presented at the present time a remunerative field, and one which had not been yet either extensively or profitably worked. The introduction of heat into water had occupied a large share of attention, but to a far less extent the removal of heat from it. There could be little doubt that through the medium of water, and the vapour of water, the greatest mechanical force was attainable; but a point would be gained for a multiplicity of processes if what might be called a dry machine could be produced for propagating and communicating reductions of temperature.

Condensation of steam by surface action on the vessel containing it had made considerable advances; but the absorption of heat was still only practically effected by the presence and application of large volumes of water.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xviii., p. 233 *et seq.*

The extent to which the production of cold, either by injection or surface application, was carried, came largely under his notice through his knowledge of the sums annually paid in the East London district for the supply of water, which was applied to no other purpose, and which with the least contamination possible went away to the sewers, merely elevated in temperature a few degrees. The process of sugar making was one in which these practices were peculiarly common; and a sum of at least £10,000 per annum was paid in the East London Water Company's district in this one line of manufacture. The process of boiling *in vacuo* had now been practised for about fifty years; but in times quite recent there had been a great endeavour to lower the temperature under which the process was conducted. Sugar was now boiled at a temperature as low as 110°; and when anything near this could be maintained, sugar was made at once into a strong, bright, granular crystalline material, instead of being, as before, carried through the earlier stages of a heavy syrup, to be afterwards clarified and made into loaves. The modern process would not be practicable without the aid of centrifugal machines; but it was the low temperature for boiling which allowed of the light bright colour being preserved, and this low temperature was only obtained by working under a high vacuum, and rapid condensation of the vapour of the syrup was necessary.

In brewing and distilling, also, large sums were annually expended in maintaining low temperatures, not only to condense the fumes of the spirits, and expedite the out-turn from any stated quantity of factory plant, but to maintain quality, flavour, and even soundness in many liquors, on which in the process of making even atmospheric temperature exercised a prejudicial effect.

All these were processes to which the supply of cold came most advantageously, and with a value in the goods apart from any share as a source of power.

As a source of power, however, the ease and rapidity of condensation were far behind what was desirable in order that the value of the machine, both mechanically and commercially, might be increased. The temperature of the whole sea in the Bay of Bengal was for months as high, or higher, than that of the condensed water or hot well of a steam-engine in northern climates, when even good proportions had been adopted; and many a steamer, that ran at a high velocity and made excellent passages across the North Atlantic, was a tub in tropical seas, not only through the defect of vacuum, but by the unfair labour thrown upon a surcharged air-pump lifting and forcing over crooked passages, and through the

ship's side, streams for which the apertures were not adapted, and with strains to which the parts were not designed.

If cold could be produced it could be maintained; and the storage of a negative power in the form of ice was attended with neither danger nor expense. Under any circumstances storage might come in aid of continuous production, and a stream of cold would strengthen greatly the condensing power of natural water in innumerable instances.

These remarks were only made in a desultory manner. The equivalents of heat and cold in their innumerable effects might be determined as sources of power above and below the datum of atmospheric pressure, and above and below the standard average temperature of any place to which a question might have reference.

January 27, 1874.

THOMAS E. HARRISON, President,
in the Chair.

The discussion upon the Paper, No. 1,364, "On the Mechanical Production of Cold," by Mr. A. C. KIRK, was continued throughout the evening.

February 3, 1874.

THOMAS E. HARRISON, President,
in the Chair.

The following Candidates were balloted for and duly elected:—John Charles Bailey, Wilson Bell, William Foulis, Alexander Moncrieff, F.R.S., and Murdoch Paterson, as Members; Henry Barratt, Henry Percy Boulnois, Stud. Inst. C.E., Edward Brailsford Bright, Massey Bromley, M.A., Stud. Inst. C.E., William Armitage Brown, George Hayter Chubb, William Conyers, William Cooper, Charles Copland, Arthur Leslie Cousins, William Crossman, Lt.-Col. R.E., John Douglas, Samuel John Dunlop, Lieut. B.S.C., John Henry Eykyn, Stud. Inst. C.E., Joseph Edward Fisher, Joseph Edward Hannah, Cecil William Edward Henslowe, Robert Rowan Purdon Hickson, William Frederick Howard, John Jackson, Philip Townshend Somerville Large, Stud. Inst. C.E., John Edgar Lowe, James McRitchie, Frederick Gother Mann, Stud. Inst. C.E., John Menzies, John Penn, Jun., Robert Pinchin, William Henry Roberts, Henry Young Darracott Scott, Major-General, C.B., R.E., William Harry Stanger, John Strachan, Stud. Inst. C.E., Louis Trench, B.A., George Albert Twynam, Edward Hamilton Vernon, Patrick Lambert Weatherhead, and Charles George Wilson, as Associates.

It was announced that the Council, acting under the provisions of Sect. IV. of the Bye-Laws, had admitted the following Candidates as Students of the Institution:—Henry Osborne Baldry, Charles Walter Scriven, Arthur Herbert Thompson, and Henry John Tingle.

No. 1,341.—"The Portslade Gas-works." By John Birch Paddon, M. Inst. C.E.

The site of the Portslade Gas-works was selected in consequence of the restrictions of the Brighton and Hove General Gas Company's Act of 1866, and possession was obtained under the compulsory powers of that Company's Act of 1870.

Immediately to the east of the entrance to Shoreham harbour there is a tract of shingle, between the sea and the canal forming the eastern arm of the harbour. This shingle has been arrested in its eastward movement by the original entrance works to the harbour. Since the construction of the existing western entrance, the shingle has been greatly wasted by the sea. Between 1865 and 1870, in front of the site of the gas-works, the high-water mark at ordinary spring tides advanced landwards 100 feet; and at high tides, during strong gales of wind, the waves broke over the greater portion of the land between the sea and the canal. The site of the works was the widest and most level portion of this land, with the highest average surface. To obtain a deposit of shingle along the sea front as a protection, and to prevent the lighter portions of the waves passing over the shingle bank, two groynes were constructed. In accordance with local custom, one of the three groynes was at a right angle to the shore. With groynes so built there is an invariable scour and waste on the lee side, so that a repetition of such groynes along the coast to be protected becomes a necessity. The second groyne was designed to prevent this destructive action, and was projected towards the east at an angle of 45° to the shore. The result has been satisfactory, for, soon after its completion, a large bank of shingle accumulated on the east side, where it has since remained. A breastwork was also constructed of creosoted Swedish timber; the section of the piles being 12 inches square, the waling and diagonal bracing 12 inches by 6 inches, and the planking 3 inches thick. At a depth of 14 feet the ends of the piles entered a stratum of sand and gravel of great density and holding power. Since the construction of this breastwork it has several times been exposed to the coincidence of a high tide and a strong gale of wind, and it has proved a suitable and efficient protection to the site. The uncovered surface of the ground has been raised to a height of 4 feet above high-water line at ordinary spring tides, and the floors of buildings from 1 to 3 feet above the outside ground line. The quantity of material put upon the ground for this purpose was 31,500 cubic yards.

A supply of water has been obtained by sinking an iron cylinder to a depth of 50 feet below the ground line. The water obtained from the chalk at this point holds in solution 500 grains per per gallon of salts (sea water containing 2,700 grains per gallon), and is available for most of the purposes of the works, except for drinking. The water tanks over the pump-room furnish storage for 20,000 gallons of water—a quantity sufficient for

ordinary operations to an extent represented by the consumption of 100 tons of coal.

The general arrangement of the buildings is shown in Plate 12, Fig. 1. Excellent material for concrete was obtained in excavating the trenches. The foundations of the walls were extended so as to make the proportion of the weight of the superstructure to the bearing surface 15 cwt. per square foot. The concrete bed under the retort benches is 7 feet 6 inches thick.

The retort-house (Plate 12, Figs. 2 and 3) is 284 feet 6 inches long, and 80 feet wide, inside measurement. Below the floor, and in front of the furnaces, are two lines of culverts for the entire length of the house, with similar culverts in communication under the gangways. In connection with these culverts a series of 12-inch drain pipes pass under the floor from the outside of the building, by which a sufficient, and easily regulated, supply of air is admitted for the furnaces, and the chief advantage of a stage floor is obtained. The culverts also contain the pipes for supplying water to the ash-pans and cisterns, and act as drains to the floor of the retort-house. A cistern of water for coke-quenching is placed at the corners of each block of retorts. These cisterns are all connected together, and, by a float valve and cistern in the pump-room the water in them is kept, without overflowing, constantly at the same level throughout the house. From each gangway a tramway descends to the coke ground, for coke-barrows to pass over. The floor of the retort-house is paved with narrow Swanage pitchers, laid in diagonal courses. A floor of this kind was in use in the retort-house at Hove for twelve years, without receiving or requiring any repair. The cost is 7*s.* 6*d.* per square yard, exclusive of the concrete bed.

The chimneys are constructed with the lower parts of brick and the upper parts of wrought iron, and are sufficiently light to be placed on the benches, so as not to occupy floor space. They are 71 feet 6 inches high, 3 feet square at the bottom, and 3 feet in diameter at the top, the least sectional area giving 1 square inch for each lineal foot of retort used in connection therewith. The working result of this proportion is satisfactory.

The retort-house is covered by a mansard roof. From the great internal capacity of this form of roof, there is a temporary detention of the vapours arising from drawing the contents of the retorts and quenching the hot coke. The more condensable of these vapours are thereby arrested, and the quantity escaping from the ventilators is consequently less than the quantity produced; but this occasions

no practical inconvenience to the men employed at the retorts. In consequence of the exposure of the roof to storms of great violence, and to rapid corrosion from the proximity of the sea, it was considered desirable that it should be of great strength, and that its parts should be few and accessible. Accordingly, the roof was designed to sustain a weight equal to 60 lbs. per square foot of external surface, or 72 lbs. per square foot of plan covered. With that weight no part is subjected to a tensile strain exceeding 5 tons per square inch of section; the strains on the parts in compression varying from 2 to 4 tons per square inch of section. The roof consists of ten Warren trusses of 84-feet span and 14 feet deep, placed about 30 feet apart. Across the top beams of the trusses there are four lines of latticed purlins, upon which purlins the bars are laid carrying the skin of the upper portion of the roof. The lower portion of the roof is formed with the framed struts of trusses, and some lighter intermediate framed struts joined to the bars immediately over them. Thrust on the walls is prevented by a series of ties, with screwed couplings, placed between the feet of the intermediate rafters and principal trusses. The laths are of channel-shaped section, and Duchess slates are fastened thereto with screwed clips, two to each slate. Four wrought-iron rudimentary shafts, 10 feet in diameter, enclosing the tops of the chimneys, allow the smoke to escape. There is also a protected opening, 5½ feet wide, along the ridge for its entire length, for the same purpose. The roof was constructed by Messrs. Newton and Chambers, of the Thorncliffe Iron-works, and its cost, ready for slating, was £8 16*s.* per square of 100 feet.

The coal stores are to the south of the retort-house, and are in connection with the system of tramways from the wharf to the retort-house. The divisional walls, which are 14 feet high, support the columns carrying the roof, and give convenient access to every part of the stock in case of fire. Under the two first of the coal stores are the tar-tanks, of a capacity together of about 200,000 gallons. The store is 180 feet long and 120 feet wide, and will hold 6,500 tons of coal without trimming. The coal storage inside the retort-house is equal to 1,500 tons. The company at present carbonise 26,000 tons of coal per annum. Of this quantity it is estimated that under ordinary circumstances 20,000 tons pass directly from the ships into the retort-house, so that the coal-stores outside are ordinarily only filled and emptied once a year. The coals are landed at a wharf in front of the middle of the site of the works. At spring tides there is a depth of 16 feet of water at the wharf, and ships of 600 tons

burden can be placed alongside. The coals are raised from the holds of the ships to the overhead tramway, or viaduct, by two steam cranes lifting 25 tons per hour per crane, and are delivered into wagons and driven to the retort-house and coal-stores. The wagons carry 10 cwt. each. A plan of the tramways is shown in Plate 12, Fig. 1. The rails are laid at a gauge of 2 feet 6 inches, and the communications with the retort-houses and the coal-stores are made by light turntables, which will be available for similar stores and a retort-house to be erected on the other side.

There are twenty-four benches of retorts. Each bench has eight long retorts, and each retort two mouth-pieces, so that there are three hundred and eighty-four mouth-pieces in all. The retorts are cylinders 16 inches in diameter and 20 feet long (Plate 13, Figs. 1 and 2); and each will carbonise 1 ton of coal per day. Allowing one-sixth of the number for reserve, the remainder will produce 1,500,000 cubic feet of gas every twenty-four hours, or 300 millions per annum. The ascension pipes are 6 inches in diameter at the bottom and 5 inches at the top. The hydraulic mains, two to each block of six benches, are of larger section than usual, and have separate outlets to the collecting main. The buckstaves are of rolled iron, with tie-rods fixed clear of the brickwork.

The gas, as it is produced, passes with the tar and liquor from the collecting pipes of the hydraulic mains, at either end of the retort-house, into 12-inch mains carried along the inside, and uniting in the middle of the south wall of the retort-house, from which point they issue by a 16-inch main to the condensers. At the end of the horizontal condensers the tar and liquor are deposited in a seal tank and led to the tar-tanks under the coal-stores. From this point the gas passes successively through the vertical condensers, exhausters, scrubbers, purifiers, station meters, and driving exhausters, into the main leading from the works to the gas-holders at Hove. The mains and connections throughout the works are 16 inches in diameter.

The condensers are shown in Plate 13, Fig. 3. The reduction of the temperature of the gas in the horizontal piping is gradual and comparatively small; but by the vertical condenser the temperature of the gas is easily assimilated to that of the atmosphere. The vertical condenser at Portslade differs from the annular condenser ordinarily used in being placed upon a ventilating chamber, in having a double set of rising pipes instead of a single set, and in being worked without open seal cups. The advantages gained

are, a control over the draught of air to the insides of the annular pipes, increased condensing surface and power, and an entire absence of smell from the liquor and tar deposited during the process of condensation.

The engine-house (Plate 13, Fig. 4) contains four exhausters, each exhauster being driven directly by an independent engine. Two of these exhausters are for the purpose of removing the gas from the hydraulic mains and driving it through the scrubbers and purifiers. A self-acting by-pass is carried from the inlet of the exhausters to the inlet of the purifiers, and each exhauster is connected with a governor, which also acts as a by-pass. Only one of these exhausters is in use at a time, the other being in reserve. The remaining exhausters are also used one at a time, and are for the sole duty of receiving the gas at the outlet of the station meter, and of delivering it into the mains leading to the gas-holders at Hove. The works are thus relieved from all pressure from the weight of gas-holders and from the resistance of the intervening mains. An hydraulic by-pass, made to resist back pressure, is placed between the meter and the main; and each exhauster is connected with a governor, whereby a slight uniform pressure is maintained at the outlet of the meter.

In the boiler-house are two of Howard's boilers each of 30 HP. The tubes are set nearly horizontal, and the boilers are entirely free from any tendency to prime. The steam from these boilers is carried through the coal-stores to the engine in the pump-room, a distance of 300 feet, the pressure of the steam being reduced in transit from 60 lbs. to 50 lbs. per square inch. A small portable steam crane in the coal-stores lifts the coals into wagons for the retort-house. Steam is conveniently supplied to this crane at whatever part of the tramways in the coal-stores the crane is required to work.

The scrubbers used at these works are the first of the kind erected (Plate 14, Figs. 1 and 2). They consist of a series of perforated discs or screens, which revolve slowly, in a tank half filled with liquor, so that the gas may pass through the portions of the screens above water. The gas is by this means divided into a series of small streams, each stream being brought equally into repeated contact with a thoroughly wetted surface. The screens being fitted at the edge with an elastic fringe, made by preference of bass, there is but little friction against the circular portion of the tank, and as no advantage is gained by a speed of more than 50 revolutions per hour, the power required to keep the

screens in motion is very small. There is a slight difference in the heights of the bases of the scrubbers, the first being the lowest and the third the highest.

In course of working, the gas passes through each scrubber from the lowest to the highest of the set. Water enters the highest scrubber and runs through the middle and lower scrubbers to the liquor tanks, the desired strength of the liquor being obtained by regulating the volume of water admitted to the highest scrubber. These scrubbers remove 95 per cent. of the ammonia, 50 per cent. of the sulphuretted hydrogen, and from 30 per cent. to 50 per cent. of the carbonic acid existing in the crude gas. They offer no perceptible resistance to the flow of gas, and are free from the disadvantages of the vertical scrubbers in ordinary use. These disadvantages are,—The inevitable clogging up of the interstices of the scrubbing material, so that the passage eventually becomes no greater than necessary for the actual volume of gas forcing its way through. The expense and difficulty of raising to the tops of the scrubbers an adequate volume of liquor; this volume, by some authorities, being estimated at one-sixteenth of the bulk of the gas. The retention of impure deposit in contact with the gas, and the impossibility of distributing liquor uniformly to the middle and lower strata of the scrubbing material. And the necessity for the occasional removal of the contents of the scrubber to obviate the obstruction to the flow of the gas.

There are seven purifiers in a line with each other (Plate 14, Fig. 3). Each purifier is 36 feet long, 18 feet wide, and 5 feet deep, with water lutes 2 feet 3 inches deep. The covers are lifted at four points, two on each side, by a travelling lift passing on rails through the entire length of the shed. In consequence of the large surface of the covers, and the occasional heavy pressure to which they are subjected, each cover is held down by four lewis fastenings (Plate 14, Fig. 4), instead of by the usual bars and clips. The lewis fastenings are easily moved and replaced, and are not liable to accidental derangement. As the purifiers are near the high-water mark of the sea, they were placed on pile foundations 3 feet above the surface of the ground, and when the pipes and connections had been laid between the piles, the spaces under the purifiers were filled up. Tramways are laid at each side of the line of purifiers, and the purifying material is brought and removed from the oxide and lime sheds at either end in wagons. The shed covering the purifiers is of light construction (Fig. 5), and is closed on the side next the sea and open on the other side. The revivifying sheds at either end

are each 100 feet long and 50 feet wide, and are fitted with framed movable louvres. The first three purifiers are for lime, the next three for oxide of iron, and the last is also for oxide of iron, to be used as a check purifier. The collective internal capacity of the purifiers amounts to 22,600 cubic feet. They are intended for a maximum production of 3,000,000 cubic feet of gas per day, being an allowance of 7½ cubic feet of purifier space for each 1,000 cubic feet of gas made per day. Although this proportion is rarely exceeded in large works, it may be taken for granted that the larger the purifiers the more economical and perfect will be the process of purification. The cost of removing the exhausted material from the purifiers and recharging them is 5*d.* per ton of material moved.

The station meter is one of the largest yet made. It was erected by Messrs. Parkinson and Son, to pass 100,000 cubic feet of gas per hour, and is placed next to the engine-house.

The gas-holders are all at Hove, and their tanks are about 34 feet above the level of the works at Portslade. The length of main between the works at Portslade and the gas-holders at Hove is 3,400 yards, of which about one-half is 16 inches in diameter, and the remainder 14 inches in diameter. At intervals of about 500 yards along the main, fixed receivers are provided, with a sliding disc on the top, for the removal of possible naptha-line obstructions, by sudden dislodgment under pressure from the driving exhauster at the works. Before the main was charged with gas, it was closed at the Portslade end, and a test gas-holder was connected to the other end. The main contained 12,042 cubic feet, and by forcing into it 722 cubic feet, about 6 per cent. in addition, the pressure on the inside of the main was raised to 24 inches throughout its length. With this pressure the loss was 1 cubic foot in five hours, no appreciable alteration taking place in the temperature of the contents of the main.

The testing office at Brighton is 2½ miles from the gas-holders, and the Company's mains extend in another direction to Lancing, a distance of 10 miles. Observations for three weeks were made, as nearly as possible at the same time at each of the three places, to ascertain the illuminating power of the gas, with the following results:—

Hove . . .	14·61 candles.
Brighton . . .	14·45 ditto.
Lancing . . .	14·14 ditto.

The entire cost of the works was £72,000; and when the pro-

posed second retort-house and coal store are erected upon the site allotted for them, the total expenditure will amount to £100,000. The works will then be capable of conveniently producing 600 million cubic feet of gas per annum at a cost of £166 per million.

The Paper is accompanied by a series of diagrams, from which Plates 12, 13, and 14 have been compiled.

[Mr. PADDON.

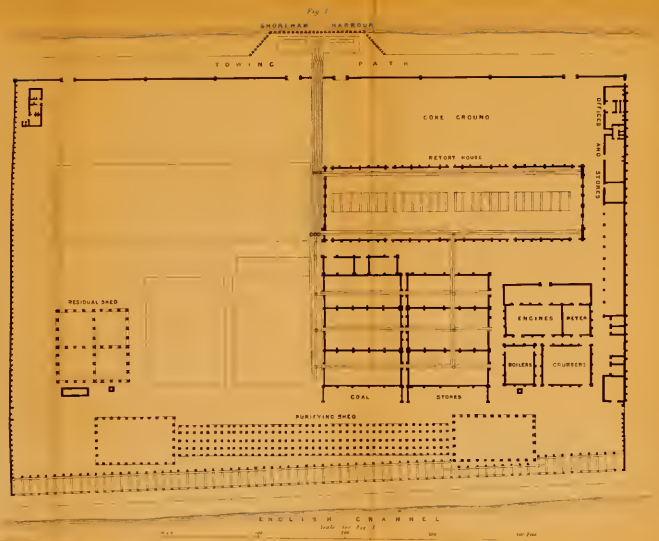
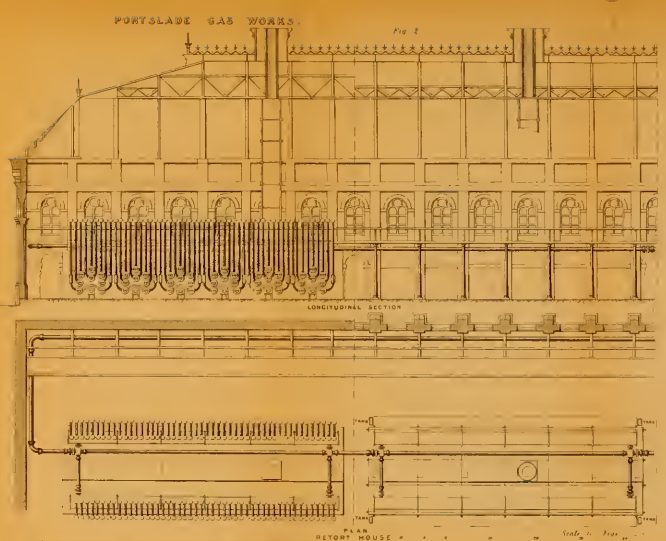


Fig 1
SHOREHAM HARBOUR
TOWING PATH
COKE GROUND
RETORT HOUSE
GAS HOLDER
RESIDUAL SHED
ENGINES
METER
BOILERS
CRUSHERS
COAL
STORES
PURIFYING SHED
ENGLISH CHANNEL


PORTSLADE GAS WORKS.
Fig 2
LONGITUDINAL SECTION
PLAN
RETORT HOUSE

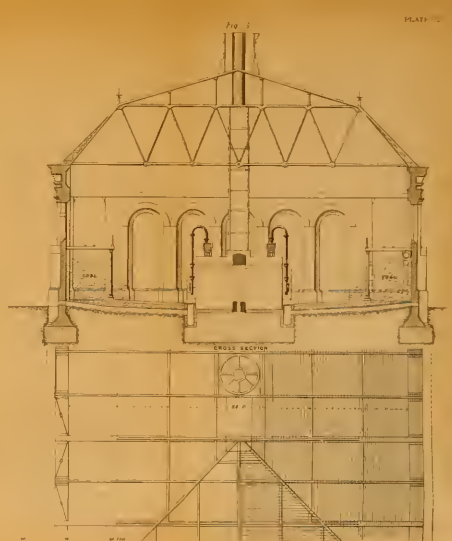


Fig 3
PLATE
COAL
CROSS SECTION
RETORT HOUSE

Fig. 1.

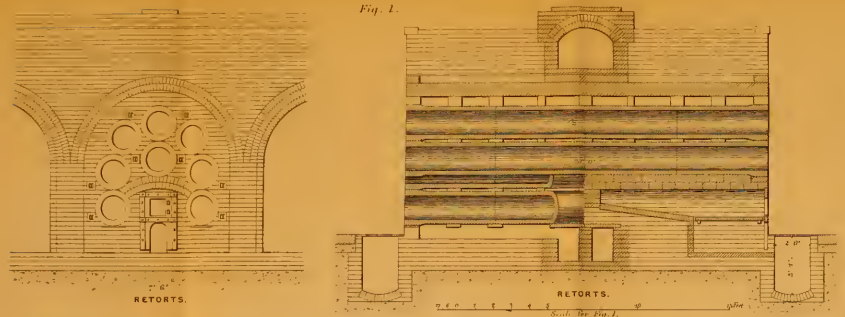


Fig. 2.

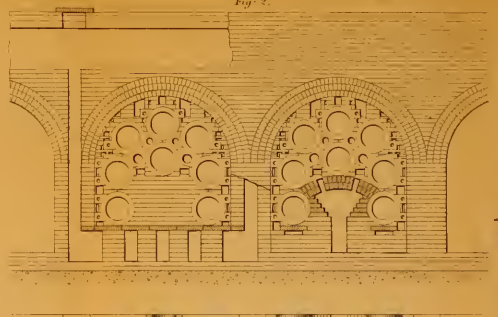
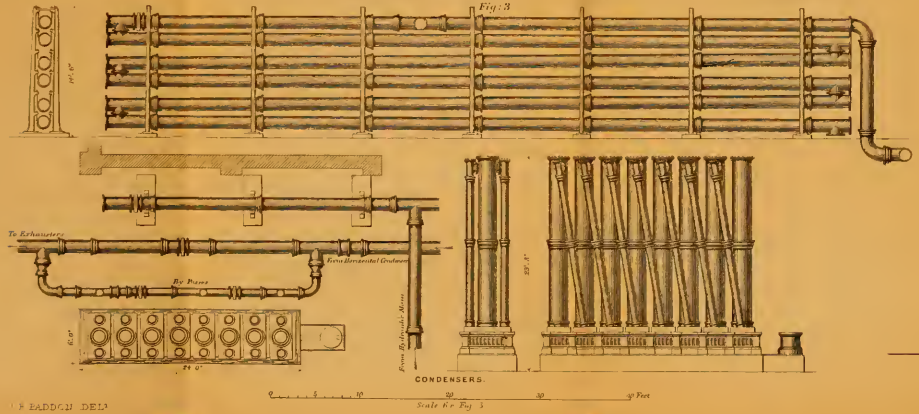
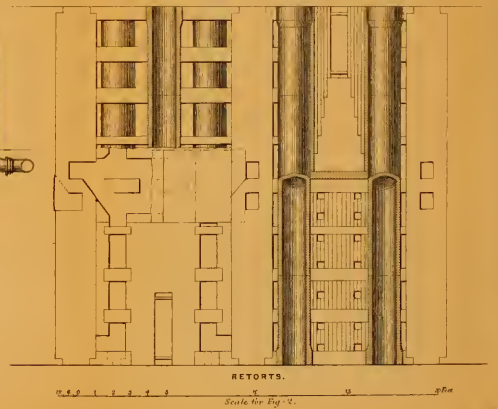


Fig. 3





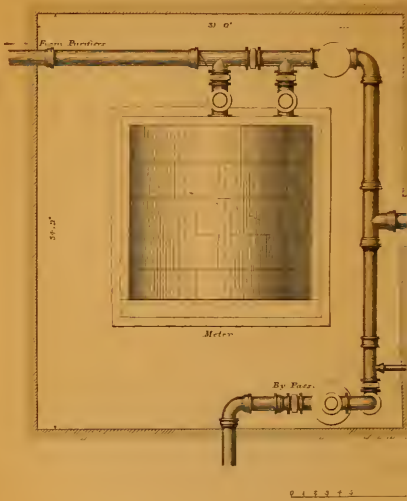


Fig. 2

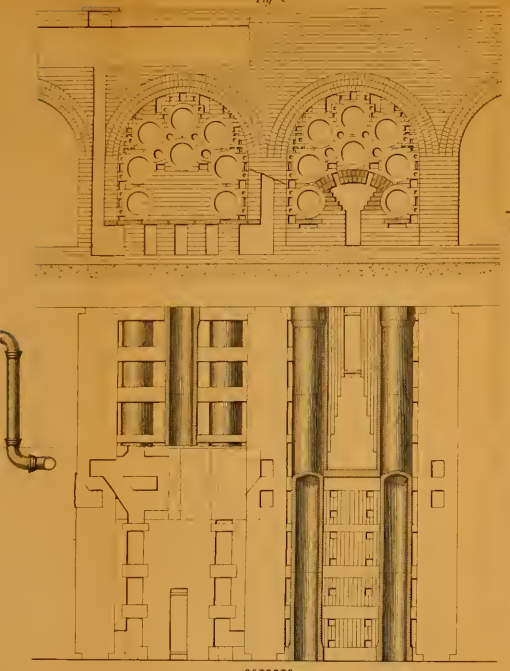

RETORTS.
Scale for Fig 2

Fig 4

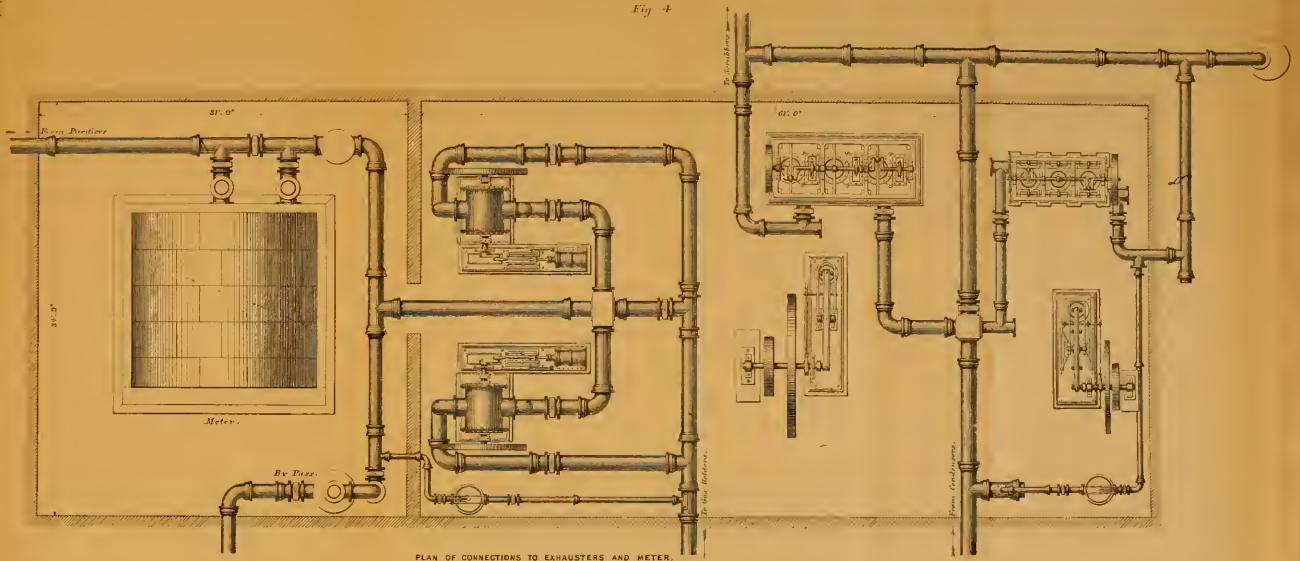
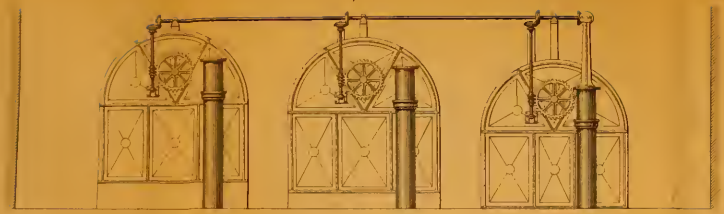
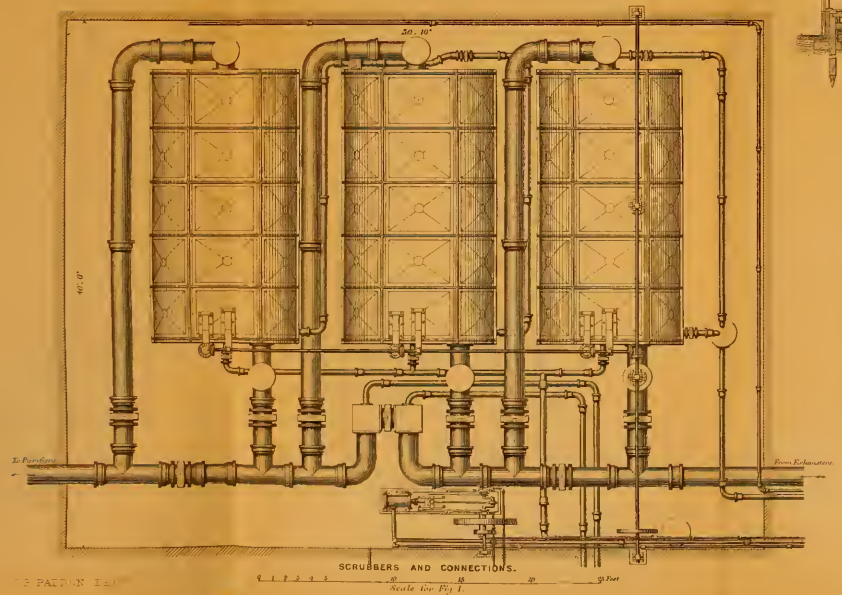

From Purifiers
Meter.
By Pass.
To Condensers
From Condensers
PLAN OF CONNECTIONS TO EXHAUSTERS AND METER.
Scale for Fig 4.

Fig. 1.

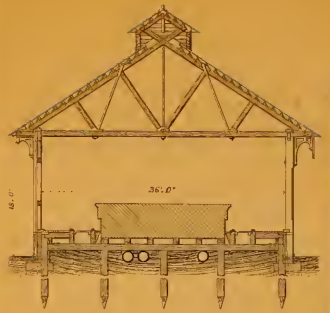




SCRUBBERS AND CONNECTIONS.

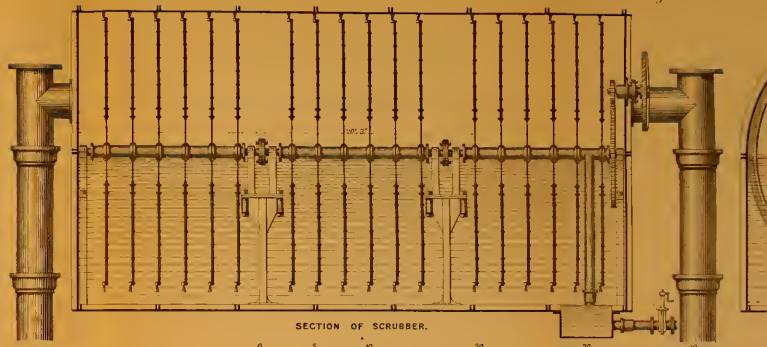
Scale for Fig 1.

Fig 5.



PURIFIERS. CROSS SECTION OF SHED.

Fig 2.



SECTION OF SCRUBBER.

0 5 10 20 30 40

Scale for Fig 2.

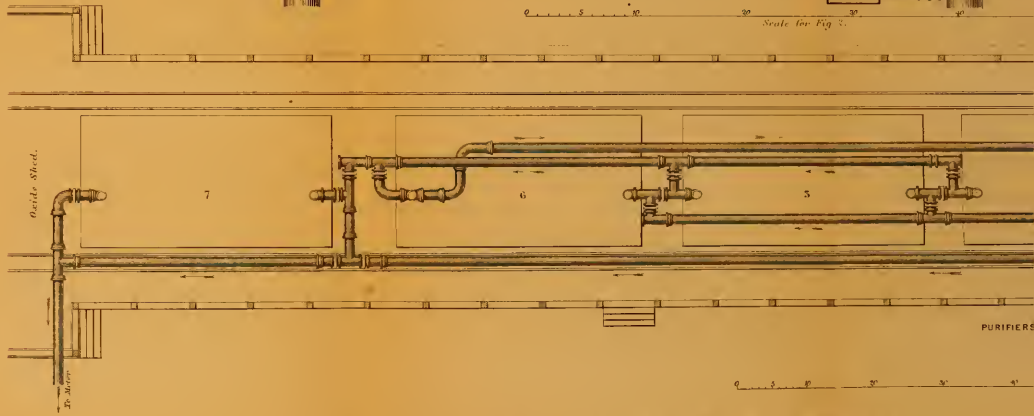
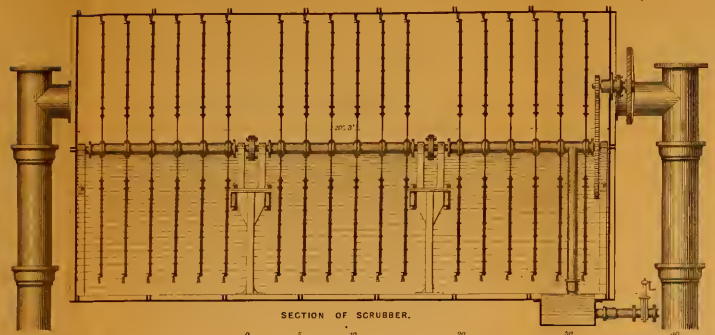
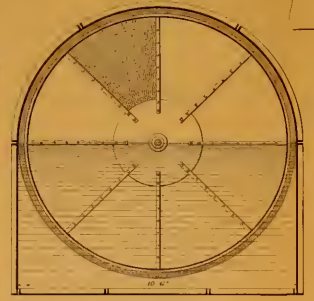


Fig. 2.

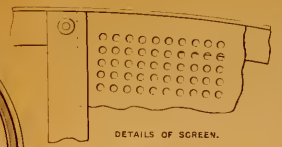


SECTION OF SCRUBBER.



SECTION OF SCRUBBER.

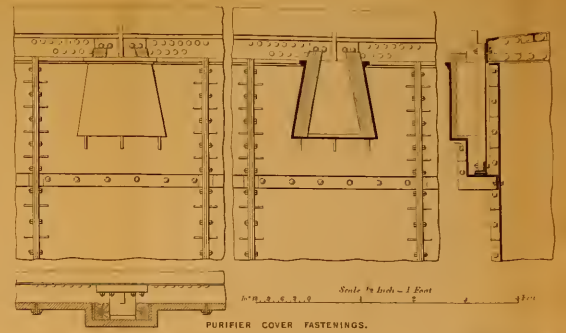
Scale for Fig. 2.



DETAILS OF SCREEN.

Scale ½ Size.

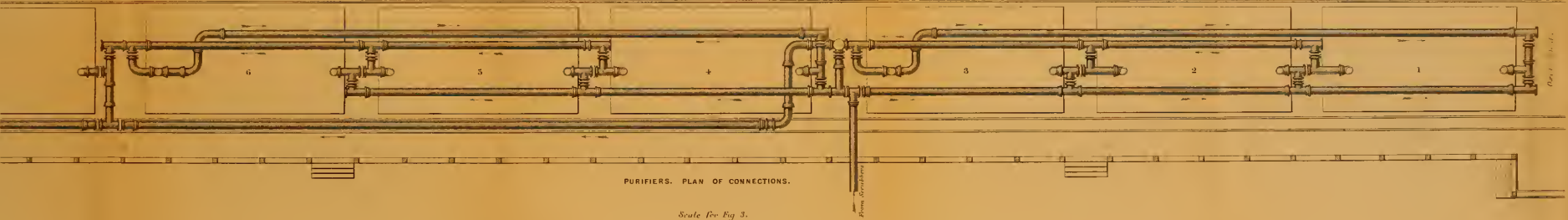
Fig. 4.



Scale ½ Inch = 1 Foot

PURIFIER COVER FASTENINGS.

Fig. 3.



PURIFIERS. PLAN OF CONNECTIONS.

Scale for Fig. 3.

Minutes of Proceedings of The Institution of Civil Engineers Vol XXXVII Session 1873-74 Part 1

Mr. Paddon hoped this Paper, which he believed was the first of the kind read before the Institution, would be followed by others upon the same subject. There was no want of materials, for in such gas-works as those at Nottingham, Liverpool, Glasgow, and notably Beckton, Fulham, and Bromley, might be found examples of interesting applications of natural laws to an extent not to be met with in the construction of ordinary railways. He should be glad to hear opinions on the comparative merits of ground floors and stage floors for retort-houses, on the most suitable form of roof for a retort-house, on the construction of condensers and scrubbers, and on the arrangement of the purifiers on the ground as compared with purifiers fixed overhead.

Mr. J. Aird, Junior, had seen the works described in the Paper, and thought them as perfect and complete as any that could be made. The use of timber in the construction of the purifying house appeared, without some explanation, to be open to objections. But the piles upon which the building was constructed had to be driven to a considerable depth, and upon those piles it might have been somewhat inconvenient to put any other than a light structure such as that described. In gas-works generally, however, the use of timber, considering its inflammable character and its liability to decay, would, he thought, be objectionable for such a purpose. The position of the works at a distance from Brighton no doubt gave greater facilities for obtaining coals, &c.; the land also was less costly, and there was less difficulty in finding accommodation for labour. On the other hand there was increased difficulty in getting rid of the coke and other residual products. The question was an important one for discussion, but he expressed no opinion upon it. With regard to the relative difficulties encountered by engineers in the construction of gas-works and railways, in his opinion, the latter sometimes presented serious difficulties, such as few gas engineers ever had to deal with.

Mr. Bazalgette, C.B., trusted the discussion would not be confined to details, but would be directed to points of vital interest to gas consumers—the cost of production, the quality of the gas, and the means of getting rid of the products.

Mr. H. E. Jones approved entirely of the scrubbers. Most exaggerated types of scrubbers had lately been erected, especially in regard to height, the idea being, he supposed, that liquor or water could not be thrown too high before treating the gas with it. Mr. Paddon's apparatus provided for the water being thrown in at a moderate elevation, requiring little effort of engine power.

The difficulty attaching to ordinary scrubbers (which the Author had not exaggerated) was to ensure the equable distribution of the liquor from the top downwards. The scrubbers at Portslade were convenient, small, and inexpensive. The best test of their efficiency would have been a statement of the results obtained in gallons of liquor of specific strength per ton of coal carbonised. He agreed as to the superiority of retort-houses constructed on the ground floor for works on a large scale. With an elevated stage there was not only the additional cost of construction (half as much again), but the expense of lifting the coals in working; and although the cost of stoking was less, it was questionable whether that saving was equal to the interest on the extra capital, especially as the retort-houses were not fully occupied except during a short portion of the year. Moreover, unless the coke could be readily sold out of the chamber below the floor, extra labour had to be employed to stack the coke outside. He was not prepared to say that in the case of works where the whole retort-house was used for more than a half or third of the year, it might not be advantageously constructed on the stage plan; but in ordinary cases that plan was a ruinous one, entailing a burden of capital on the company which a small saving in wages would not recoup. The principal of the roof of the retort-house seemed to suggest a straight girder, in which the expansion would not be provided for as in the ordinary gable form of principal by a rise in the pitch. He should be glad to know whether any provision had been made to prevent thrust upon the side walls in consequence of the expansion and contraction of the girder. He had visited the works, and considered them to show the hand of a skilful workman. The desire had evidently been not to make fancy works, or not to seek for architectural fame, but to provide for the most profitable manufacture of gas.

Mr. Horatio Brothers strongly objected to the roof of the retort-house. On examining recently a roof of a similar description at the Western Gas-works, he found it to be simply a smoke-trap, so that on a foggy day the men could hardly see how to go about their work. He had to put dormers in the roof and open out windows in the wall, to secure ventilation and get rid of the smoke. The work had since been carried on much more comfortably. He thought the scrubbers were inferior to those of Mr. Mann, which were provided with a distributing apparatus at the top. He had found the latter extremely effective, and he did not think there was any objection to their height. In his opinion the scrubbers at Portslade would not completely free the gas from ammonia.

Mr. R. Harris considered the scrubbers novel in construction, and possessing considerable advantages; but he wished to know whether by the method employed the whole of the ammonia could be removed from the gas. Although clean water was continually poured into the last vessel, it appeared to him that a certain amount of ammoniacal liquor must be left behind. The test of the value of any particular form of scrubber was the amount of liquor of a specific strength produced per ton of coals. There were forms of scrubbers in use in which the system of distributing water was so perfect, that the whole of the ammonia could be removed from the gas. With reference to retort-houses, he preferred the ground floor, if there was sufficient room outside, immediately contiguous to the house, for the deposition of the coke as it was removed. The loss entailed by the conveyance of gas along mains to a distant point was very trifling, either in regard to quantity or quality.

Mr. Woodall thought the Author must have been exceedingly hard driven for a site when so awkward a position had been selected; and therefore all the more credit was due to him for having constructed such admirable works. The retorts, he thought were best situated on a stage, as the manufacture had to be carried on in all weathers, and it was extremely inconvenient for the men to come out of a hot retort-house with a barrow of coke, and quench it with cold water. There was also a considerable saving in the working expenses from not having to wheel the coke to a distance. When it was drawn from the retort it fell into a chamber, and was at once stored till removed; and as a rule there was no necessity for removing it till sold. The additional expense was only in the first construction, while the saving was constant; and it did not require a considerable difference in the cost of working to make up the interest on the additional capital. It was often impossible to have a number of openings from the retort-house, to enable the men to leave without passing one another; and in that respect it was a decided advantage to store the coke under the place where the men were working. The scrubbers were likely to accomplish the work for which they were designed in an effective and economical manner. He could hardly understand the objection to the construction of the roof. Its very capacity was an advantage; and ventilation was more a matter of design in providing for the inlet and egress of the air, than dependent on the actual form of roof.

Mr. H. P. Stephenson regarded the gas-works at Portslade with

satisfaction, because the economical problem had been solved, of supplying gas of sixteen candles, at 3*s.* 6*d.* per thousand, to pay the maximum dividend to the shareholders. An important matter in the construction of gas-works was the setting of the retorts, and the work obtained from them. At the Sydenham works, where a satisfactory result had been obtained, there were through retorts, 20 feet long, in beds of seven ovals, 21 inches by 15 inches; and they were charged with such an amount of coal as to produce, in twenty-four hours, 6,200 feet per mouth-piece, on an average of six months' working. That result (which he believed to be unequalled) was produced with 15 per cent. of fuel at a chaldron to the ton. He had always found that a high make per mouth-piece gave a high rate per ton. With a high make per mouth-piece there was a decrease of labour; and with a high make per ton there was a more economical working. He believed the circumstance that Parliament had driven the Company into the site selected would lead to great economy in working.

Mr. Jabez Church considered these works second to none in the kingdom. The construction of a retort-house on the ground floor was a matter well worthy of consideration. The cost was less, and the workmen were more comfortable. With a large volume of heated coke below, much sulphur must be given off in a free state, which could not be otherwise than injurious to the health of the stokers. It was formerly the custom to erect one or two high chimney-stacks; but that principle had here been disregarded, and the plan, now usually followed, of short chimney-shafts had been adopted. He had laid down the rule of 1 inch superficial area for every foot of retort in length. That rule would apply very well where there was free space for ventilation, otherwise he thought it would be desirable to have a little more superficial area. He could not regard the roof as a "smoke-trap," but thought it well adapted to the position, though it might not be applicable in every case. Further information was needed with regard to the scrubbers, for it appeared that 5 per cent. of ammonia still remained. He believed it was possible to extract all the ammonia: and he did not think the Gas Referees in London, who kept the engineers fully up to the mark, would allow 5 per cent. to remain. The removal of these works to a distance was a necessity; and the object in selecting the site in question no doubt was to allow of access to the canal, so that the coal might be unloaded at a cheap rate. Originally the coal was unloaded at Shoreham, and carted at a considerable expense, amounting to 5 per cent. of the interest on the capital for the entire works.

He thought the lessened cost of coal in the first instance, and the facility for unloading without carting, more than counterbalanced the value of the residual products. Another point of importance was the small amount of leakage from the arterial mains from the works to Hove, which, under the heavy pressure of 24 inches, was only 1 cubic foot in five hours. That seemed to him to be the perfection of mainlaying. Where the leakage was excessive, there was of course so much loss to the revenue. With regard to the illuminating power, the first experiments at the works gave 14·61 candles; at the station at Hove it was 14·45 candles; and at a still farther range at Lancing it was 14·14 candles; so that the loss was not worth consideration, notwithstanding the distance traversed.

Mr. A. F. Wilson deemed the arrangements of the works to be very complete; but he should like to know the cost, not only of the entire works, but of the separate parts. The manufacture of gas had, no doubt, been greatly improved of late years; but too many things were done by the "rule of thumb." The carbonisation of coal was not studied with the requisite amount of close attention, nor was the gas reduced to a standard temperature before being purified. He did not think a large manufacture of gas per mouth-piece was necessarily a large manufacture per ton of coal. Generally, by overstocking the retort the coal was not carbonised as it ought to be, and the manufacture of gas per ton was lessened. According to his experience it was better not to overstock the retort—to spend a little more for wages rather than to effect a saving per mouth-piece.

Mr. H. Finlay said he had an experience of twenty years in working retorts on the ground-floor; but within the last few months he had erected a stage retort-house, on the principle adopted at the works of the Chartered, the Imperial, and other Companies. He believed that small works, making 250 or 300 millions, if there was plenty of room, could be worked with greater advantage by retorts in ground settings; but where the make was large he thought stage settings were preferable. No doubt the first cost was considerable, but the work was done more efficiently and quickly. The retorts were not so long open, and consequently turned out more gas. In large works, when cramped for room, there was a difficulty in working retorts on the ground-floor. During the last two or three years, especially since the School Board had been in operation, he had some difficulty in getting the men to take out the coke at all. Within the last few weeks several men had refused to do so, and he was obliged to take them

before the magistrates, who gave them twenty-one days' imprisonment. The fumes to which allusion had been made had never been objected to; and he did not think they were worse than the steam from red-hot coke when water was poured upon it. It was fortunate that the site in question had been selected, as coal was thus delivered more cheaply. As to lifting the coals, his own case was this. There was one stage house, and one with ground setting. In the latter the railway was higher—say 16 or 17 feet; in the former it was about 6 feet, bringing it on a level with the jetty. The coals had to be lifted, and it did not cost a farthing more to put them into the stage house than it did to put them in the house with the ground setting.

Mr. J. G. C. Godsman said he knew gas-stokers were strongly of opinion that men should not be put to do anything that machinery could accomplish; and he hoped that contrivances would be produced to prevent men from acting as mere beasts of burden.

Mr. Church remarked that in the Glasgow works, the difficulty of carting coke from the retort-house in wet weather had been readily overcome. An iron truck containing coke on a platform was lowered by hydraulic pressure, submerged, drawn up again, and by a series of tramways taken out by horse power.

Mr. Paddon, in reply, said he had not lost sight of the possibility of conflagration in employing timber for the purifying-house; but he thought the danger was very remote, and he preferred to take the risk. It could be burned down and built up again many times with the difference in cost between the timber structure and a more permanent building. A stage floor for the retort-house would have cost £5,000 additional, and he could not see where the interest of the money was to come from. In larger works there might be advantages in connection with stage floors, but he thought their value as coke stores had been much overrated. With regard to the roof of the retort-house, he thought more highly of it than of anything else in the works. There was no resemblance whatever between it and the roof of the Western Gas-works, except that they both let out the smoke at the top. During two years gas-making the men had never been inconvenienced by the smoke, and if they had it would have been quite easy to enlarge the openings and let it out. With regard to the efficiency of the scrubbers, the average amount of liquor produced per ton of coals was about 20 gallons of 10 oz. strength. If he chose to erect a fourth scrubber, he could easily remove the remaining ammonia; but he preferred to use a small quantity of material in the bottom of the

purifiers, which effectually removed every trace of ammonia. The advantage obtained by these scrubbers was that 95 per cent of the ammonia was removed more cheaply and easily than by ordinary scrubbers, and without the serious evils which had been described as existing in the ordinary scrubbers. The figures he had given with regard to the main-laying were taken with great care and were perfectly reliable. The works when completed would cost about £160 or £170 per million—a rather low figure, he thought, in comparison with other works. Further extensions could be made at the rate of £500 per million, of which £180 would be for the producing works, £80 for gas-holders, and the remainder for the distributing apparatus.

February 10, 1874.

THOMAS E. HARRISON, President,
in the Chair.

No. 1,376.—"On the Construction of Harbour and Marine Works with Artificial Blocks of Large Size." By BINDON BLOOD STONEY, M.A., M. Inst. C.E.[1]

THE attention of engineers has been frequently and forcibly directed to the great cost of temporary works in engineering operations under water. In numerous cases, especially when the foundations are laid within coffer-dams at a considerable depth below the surface, the cost of the temporary works is found to equal, or even to exceed, that of the permanent structure. It occurred to the Author, many years since, that a large share of this expense might be saved by using artificial blocks of such magnitude as rapidly to bring a pier or quay wall above low-water level. In this way coffer-dams, staging, pumping, and all the incidental expenses connected with the old system of getting in foundations under water, might be dispensed with. Similar advantages should follow where setting masonry by means of divers has been the practice; for the great expenditure of time and labour involved in this method of building under water would be avoided. Indeed, one large block might be laid in little more time than would be occupied in setting a stone of a tenth of its bulk, and with the certainty, as far as the large block is concerned, that there would be no open joints or irregular beds to cause anxiety about its future permanence. Each monolith would be self-contained, and would settle in mass without endangering the stability or cohesion of neighbouring blocks, whilst its great weight would guarantee it against disturbance from waves. Where the ground is naturally level, only one special appliance is required for the new method of construction, namely, floating shears to lift the blocks off their building wharf, and convey them, when afloat, to their destination. If, however, as in the case of the quay walls which the Author is at present constructing, it is necessary to have an artificially-levelled foundation in order that the blocks may range accurately, and lie in close

[1] The discussion upon this Paper extended over portions of two evenings, but an abstract of the whole is given consecutively.

contact with each other, a second special appliance is required, namely, a diving-bell for excavating and levelling the ground. Thus only one, or at most two special appliances are required, and the simplicity of the method is one of its greatest recommendations.

The quay walls now in progress in Dublin form a portion of a large tidal basin and other works connected therewith. They were designed by the Author in 1861, and with various interruptions and suspensions from causes unconnected with engineering, have been slowly progressing from that date until recently, when more activity has been shown. The floating shears and diving-bell were constructed in 1864-65, but were not used until the spring of 1871. The basin is rectangular, with an entrance opening into the river at the south-east corner. The range of tide in Dublin seldom exceeds 10 feet, and gates therefore are unnecessary. The water area of this basin will be nearly 50 acres, its proposed length and breadth being 2,500 feet and 850 feet respectively. The blocks, when laid in place, reach from 24 feet below to 3 feet above equinoctial low water, their total height being 27 feet. They are 21 feet 4 inches wide at the base, and 12 feet long in the direction of the wall; and when set in place, 12 lineal feet of the quay are laid at one operation up to ordinary low-water level. Each block contains nearly 5,000 cubic feet of material, and weighs 350 tons. The upper portion of the wall above low-water level is built in the usual manner by tidal work, and is faced with granite ashlar, to give a smooth bearing for ships. It is coped with granite, each block of which weighs from 2 tons to 4 tons. The total height of the wall is 42 feet 10 inches. Vertical grooves, 3 feet wide and 18 inches deep, are formed in the sides of each block; and when two blocks are placed side by side these grooves make a long rectangular tube, 3 feet square, one half in each block, into which concrete is thrown, which acts as a dowel, and effectually plugs up the small interval between block and block. These concrete dowels are introduced as an element of safety rather than as an essential matter, as, no doubt, the blocks would act very satisfactorily if the dowels were omitted. The blocks are built on a timber wharf (Plate 15, Figs. 1, 2, 3) on the north side of the basin, about $\frac{1}{3}$ mile from the new quay. This wharf is 461 feet long, and is constructed of whole balk sheet piles with a double row of whole balk wales in front, which are strongly tied back by $2\frac{1}{2}$-inch round iron tie-bars to a parallel row of 3-inch sheet piles driven about 22 feet in the rear. The interval between the rows of piling is filled with gravel and clay dredged from the bed of the river.

This wharf has proved perfectly capable of sustaining the enormous weights placed upon it. A layer of 3-inch planks is secured to sleepers imbedded in the top of the filling to form a level platform on which the blocks are built, and as spring tides overflow the wharf, these planks prevent the filling from being washed away in rough weather. The outer face of each block next the shipping is formed of calp limestone, found in the neighbourhood of Dublin, which has smooth quarry joints, and is tolerably easily squared. These face stones are set in mortar composed of 4 parts of sharp sand, and 1 part of Portland cement. The hearting of the block is chiefly done by unskilled labour; and is a class of work successfully used by the Author for many years in quay walls and similar massive masonry. It consists of stones weighing from 2 tons downwards, just as they come from the quarry, and placed, not on their flat beds as masons prefer, but on their ends as starts, or on their edges like slates when stacked upright in a yard, and bonding in every direction without any regular coursing. Especial care is taken not to lay any stone with the hollow side beneath, like a saucer upside down. On the contrary, a stone is placed with its convex side down, or on its pointed end and every interval is filled up with concrete, into which smaller stones are rammed to form a compact mass. For this purpose tamping irons, with small T heads something like a pavior's slice, and wooden rammers and shovels, are used in preference to trowels. Nothing can exceed the soundness and closeness of this work, which has been proved wherever a mass of it was broken out. This is always done with the greatest difficulty, the large stones generally fracturing in preference to the concrete, owing to the cohesion and toughness of the latter, and the broken surface presents the aspect of amygdaloidal conglomerate. The concrete is made of 1 part by measure of Portland cement to 7 parts of ballast dredged in the harbour. The ballast is a limestone gravel, with a large proportion of sand, and is not as coarse as could be desired. If it were coarser, a proportion of 1 part of cement to 10 parts of ballast would be strong enough. The sides and rear of each block are defined and kept in shape by wooden panels, which are removed when the block is built, and used over again. A block takes from three to four weeks to build, and is considered sufficiently consolidated to move after ten weeks. The length of each block, as already stated, is 12 feet, and this size is preserved for 2 feet in from the face. It then tapers about 2 inches on each side to the rear, to give a little latitude in squaring the blocks at the time of setting, and thus to insure the range being accurately maintained without having an open joint on the face. Two cast-iron

girders, weighing 11 cwt. each, are laid on the platform, and built into the bottom of each block. These girders act as washers to spread the local pressure of the suspender-bars, which support the block, and connect it with the lifting chains, over a large area of the masonry (Plate 16, Figs. 3 and 4). The suspender-bars are of wrought iron, 5 inches in diameter, and 31 feet long, with T ends at both the top and the bottom. Two rectangular holes are formed in each girder, and over each hole a tube of boards is placed vertically, round which the masonry is built; so that there are four rectangular tubes, each 20 inches broad by 11 inches wide, passing vertically through the heart of the block. When the block is ready for lifting the suspender-bars are dropped down through the tubes, and turned at right angles, so that their T ends catch in the girders below, and thus take the bearing of the block. After the block has been set in place the suspender-bars are turned round 90°, and withdrawn, to be used for other blocks as before. Each of these bars was proved to a tensile strain of 150 tons, or nearly 8 tons per square inch. The aggregate proof strain of the four bars is therefore 600 tons, and, as their calculated breaking strain is about 1,600 tons, the coefficient of safety is 4·5.

Floating Shears (Plate 16, Figs. 1–5).

The hull of this vessel is rectangular in section (Fig. 1), 48 feet wide, and 14 feet deep. It is rectangular also in plan, with the exception of the bow, which is semi-circular (Fig. 2). The forefoot has a rise of 2 feet, to enable the vessel to approach the block-wharf at or near low water without touching the ground. The length over all is 130 feet. A tank at the stern occupies 30 feet, the deck of which is 3 feet higher than the rest of the vessel, and presents the appearance of a low quarter-deck. The hull is strengthened by two transverse bulkheads of the ordinary construction, 24 feet from each end. Two double-webbed plate girders, each 3 feet wide and 18 feet asunder, run fore and aft from end to end of the hull, dividing it longitudinally into three parts, and distributing the great pressure of the shear legs over the whole length of the vessel, the iron deck and bottom of which act as flanges to the longitudinal girders. The ends of the hull and the transverse bulkheads also transfer a portion of the shearing strains to the sides, and bring them and the adjoining parts of the deck and bottom plates also into action as girders. The hull may thus be regarded as a powerful tubular girder with several vertical webs, which distribute the shearing strains over its whole area. The bottom plates are $\frac{1}{2}$ inch thick, with butt joints throughout, the cross joints having inside

covers, and the longitudinal joints outside strips, which lie in the direction of, and therefore take a share of, the longitudinal strains. The floors are formed of $\frac{3}{8}$-inch plates, 15 inches deep, and 2 feet apart from centre to centre, with 3-inch by 3-inch by $\frac{3}{8}$-inch angle iron at the top and bottom. The sides of the hull are $\frac{3}{8}$-inch plates, clincher built, and the frames are 5-inch by 3-inch by $\frac{1}{2}$-inch angle iron, 2 feet apart from centre to centre. The bilge angle iron, connecting the sides and bottom, and the gunwale angle iron, connecting the sides and deck, are $3\frac{1}{2}$-inch by $3\frac{1}{2}$-inch by $\frac{1}{2}$-inch angle iron. The deck plates are $\frac{3}{8}$-inch thick, flush on the top, with longitudinal and transverse straps underneath the butts. The deck beams of the side compartments are 4-inch by 3-inch by $\frac{1}{2}$-inch angle iron, and those of the centre compartment are 6-inch by 3-inch by $\frac{1}{2}$-inch, secured to the frames and to the longitudinal girders by $\frac{3}{8}$-inch gusset plates. The transverse bulkheads are formed of $\frac{3}{8}$-inch plates, stiffened with angle-iron frames, 5-inch by 3-inch by $\frac{1}{2}$-inch, 2 feet apart from centre to centre.

The tank has the same beam as the hull, and is 30 feet long and 17 feet deep. The floors run fore and aft, and are formed of $\frac{3}{8}$-inch plates 2 feet deep, with double reverse angle irons, 3 inch by 3 inch by $\frac{3}{8}$ inch. Four of these floors, which are in the line of the longitudinal girders, have $6\frac{1}{2}$-inch by $\frac{1}{2}$-inch flange plates riveted to the reverse angle irons, so as to strengthen the upper flanges of the floors, and give them greater strength as pillars, to withstand the horizontal component of strain in the suspenders which connect the end of the tank with the aft shear legs. A considerable quantity of concrete in the bottom of the tank overcomes its displacement when the water is pumped out, and concrete is also placed as ballast between the floors of the hull, to increase the stability of the vessel.

The framework above the deck consists of two pairs of shear legs, with powerful backstays reaching diagonally from the top of each pair to the feet of the other pair (Fig. 3). The forward shears support the block hanging from the chains, those aft support the tank. It will be observed that the centre of the block is 15 feet from the bow of the vessel, and that the centre of the tank is also 15 feet from the stern of the hull. If, therefore, a block be suspended at one end, and water to balance it be pumped into the tank, and the vessel floated on an even keel, the total weight supported by the hull will be twice the weight of the block. The peculiar arrangement of a double set of shear legs may require explanation. First, if a pair of shear legs is the most efficient arrangement for supporting the block at one end, a similar pair seems an equally good plan for supporting the tank at the other end; secondly, the local pressures

in this machine are of an unusual character. For instance, when a block is hanging from the chains, there is a thrust of about 700 tons passing downward through the forward pair of shear legs, tending to punch them through the bottom of the vessel. The vertical component of strain in the second pair of backstays, being in the opposite direction, balances a considerable portion of the downward thrust in the legs, and so far relieves the great local pressure at their intersection on the deck. The shear legs are rectangular tubular pillars, with double angle irons, 4-inch by 4-inch by $\frac{3}{4}$-inch in each corner, as the Author's investigations have led him to conclude that the strongest form of rectangular pillars is one in which the great mass of material is placed in the corners, the chief duty of the sides being to act as a web, and to keep the corners in the line of thrust and preserve them from flexure. The legs are 3 feet square at the foot, and 3 feet by 2 feet at the top, the taper being on the outside, to keep the insides parallel. The sectional area at the top of each of the fore legs is 126 square inches, and the compressive strain is very nearly $2\frac{3}{4}$ tons per square inch. As three-fourths of the whole section of each leg is concentrated at the corners within a distance of 10 inches measured from the angle, the mass of the material has been placed as far as practicable at a distance from the axis of the pillar. Each pair of legs is braced together by cross struts and diagonal ties, which stiffen them sideways, and any tendency to sag from their own weight in the fore and aft direction is prevented by light tie-bars.

The sectional area of the aft shear legs which support the tank is a little less than that of the fore legs, being 102 square inches at the top. The diagonal backstays are H-shaped, formed of $\frac{1}{2}$-inch side plates, 34 inches wide, with a T-iron, 6 inches by 4 inches by $\frac{1}{2}$-inch, running along the inside of the centre of each, and braced across with light internal lattice bars, $2\frac{1}{2}$ inches by $\frac{3}{8}$ inch. Theoretically no stiffening is required for these stays; but it is requisite to prevent them from vibrating with the wind. The gross cross section of each stay, omitting the internal lattice bars, is 50 square inches; the net section is about 41 square inches, and the working strain is nearly $4\frac{1}{2}$ tons per square inch of net section. The suspender stays which support the tank are similar in general design, but lighter than the diagonal back stays. A strong double-webbed cross girder rests on the top of the forward shears, and supports the upper sets of pulleys through which the chains are reeved. This cross girder has to sustain a severe transverse strain, due to its own weight and that of the block, chains, pulleys, and suspender bars, &c., amountnig to over 450 tons, or, approximately,

the weight of eighteen ordinary locomotives piled on the top of each other. The total height from the deck to the upper flange of this cross girder is 53½ feet, and the horizontal distance from the bow of the vessel to a vertical dropped from the centre is 15 feet, so that the centre of a suspended block is 15 feet from the vessel when the latter is on an even keel. The lifting chains are pitch chains, formed of one and two flat links alternately, and weigh 46 lbs. per lineal foot; they are controlled independently of each other by powerful crab winches bolted to the deck. The sectional area of the links is 6¾ square inches in the waist, and the pins are 2½ inches in diameter; the length of the link, measured from centre to centre of the pins, is 11·48 inches, and the length of each chain is 645 feet; they were tested to a proof strain of 35 tons, and their breaking strain is 112 tons. The breaking weight of the bar iron of which the chains were made was 22 tons per square inch, and its ultimate elongation, or set after fracture, was a little over 17 per cent. Each chain has eight parts, or sixteen parts in both chains together, so that each part has theoretically to carry only $\frac{1}{16}$th of the total suspended weight, or nearly 24 tons; but, with an additional allowance of $\frac{1}{6}$th for moving friction, the maximum working strain will be 28 tons, or $\frac{1}{4}$th of the breaking weight. Each chain is reeved through two sets of four-sheaved pulley-blocks, 4 feet in diameter (Fig. 4). The upper set of blocks rests on the top cross-girder, the lower set hangs beneath in the air, and has a pair of forged cross-heads bolted to the lower part of the wrought-iron plates forming the cheeks of the sheaves. The suspender bars, which pass through the block of masonry as already described, can pass freely in one direction between these cross-heads; but when turned at right angles their T ends catch on the upper surface of the cross-heads, and are raised along with them when the chain is hauled in. The downfall of each chain passes from the upper set of pulley blocks to a toothed barrel on the main shaft of a powerful crab winch placed on deck, and thence over a guide pulley, from which it descends beneath the deck, where the slack would soon kink and become an inextricable tangle if it were allowed to pile up like an ordinary chain in a chain bunker. To prevent this, the slack chain is wound backwards and forwards over two sets of sheaves attached to the extreme ends of the engine room. This coiling operation is effected by a separate donkey engine and crab winch for each chain, which coils up on a drum a ¾-inch close-linked chain attached to the free end of the large pitch chain, and drags it backwards and forwards over the fixed pulleys as fast as the slack comes in from above. The donkey engines accommodate them-

selves to the varying speed of the pitch chains, running fast when there is much slack, and going slowly, or stopping gradually, when the chains come in slowly or are stopped. This gradual stoppage of the coiling engines is effected in the following manner: the pitch chains descend from the deck to the floor of the engine room with a catenary curve, which acts like the spring of a cable, and pulls up the little engines gradually and without jerk to any part. When the large chains are going outboard the coiling barrels are thrown out of gear, and the spare chain below is uncoiled and hauled up again by the reversed motion of the large crab winches on deck. With this exception, all the work is done by an ordinary horizontal high-pressure engine of 14 nominal HP., placed in the central compartment of the hull, which drives the large crab winches on deck, a centrifugal pump in one of the side compartments for filling or emptying the tank, and six large surging heads on deck for hauling in the ropes by which the vessel is warped from place to place. The boiler is in the aft part of the engine room, and is an ordinary multitubular boiler, 14 feet long and 5 feet 9 inches in diameter, the steam pressure being about 45 lbs. per square inch.

Diving Bell (Plate 15, Figs. 4–7).

The second special appliance used in the works under consideration is the diving bell. The chamber is 20 feet square at the bottom, 16 feet square at the roof, and 6½ feet high inside, formed of twenty-five massive castings, with planed joints, bolted together with 1½-inch screw-bolts, spaced 8 inches apart from centre to centre. From the centre of the roof rises a tube or funnel of ⅜-inch plate iron, 3 feet in diameter and 37½ feet high, with a hand-rail round the top. The total height of the chamber and funnel is 44 feet; and this is the greatest depth of water in which the bell can be worked at present, though, by adding to the length of the funnel, it might be used for greater depths. The upper end of the funnel forms an air-lock 6½ feet high, with suitable cocks for admitting the compressed air from the chamber into the lock, or for letting that in the lock escape into the external atmosphere. The door-frames of the air-lock are of cast iron, 2 feet in diameter in the opening, and bolted to angle iron rims riveted inside the funnel. The doors are of ½-inch plate iron, with india-rubber rings where they bear against the circular lip of the frame; and each door has in the centre a round light of thick plate-glass 8 inches in diameter. There are also three rectangular side lights near the top of the

funnel, each 12 inches long by 4 inches wide. In addition to these deck and side lights, which transmit a certain share of daylight down through the funnel, there are sixteen rectangular plate-glass lights in the roof of the chamber itself. When at work in deep or muddy water, paraffin candles are used inside the chamber; but the eye gets so accustomed to the dim twilight, that the men occasionally dispense with artificial light, and thus avoid the smoke which hydro-carbons produce in a greater degree under pressure than in the ordinary atmosphere. Ladder-rungs are fixed on both the outside and the inside of the funnel. A flexible air-pipe of $2\frac{1}{2}$ inches bore leads from the air-pump on board the barge, and is coupled, below the bottom of the air-lock, to the nozzle of a 3-inch wrought-iron pipe, which passes down the inside of the funnel, then along the ceiling, and down one corner of the chamber to within about 10 inches of the bottom. Supposing an accident were to occur, such as the rupture of the flexible air-pipe, or the stoppage of the air-pump, the water would rise inside the bell only as high as the lower end of the iron pipe, which would then be sealed, so that the water could not rise higher, and the men would have time to come up the funnel at their leisure, and pass out of the bell. The clerk of the works can also pass in or out at any time while the men are working, to see what progress is being made. Inside the chamber two large sheet-iron trays, 11 feet long, 4 feet wide, and 18 inches deep, are suspended by chains from the roof. These trays are hung on gimbals, and on knocking up a detent they tilt and discharge their load. A dial on the outside of the top of the funnel, with a pointer and a bell to call attention, corresponds with a dial and pointer inside the roof of the chamber; the two pointers are connected by a vertical shaft of thin gas-tubing, passing through a stuffing-box in the roof. The signals required are, "Raise," R.; "Lower," L.; "North," N.; "South," S.; "East," E.; "West," W.; and full stop "●." The operation of excavation is simple. The bell rests on the bottom, and the men shovel the stuff into the trays. When these are filled the ganger below turns the signal-handle to the letter R., and the bell is lifted a few feet off the ground; the barge is then hauled some yards to the rear of the wall, into the proper position for discharging, and the deck man gives a knock on the side of the funnel as a signal to the man below to release the detents and discharge the stuff. The barge is then hauled back to its original position, and the bell is lowered again. The bell, which weighs $80\frac{1}{2}$ tons, is suspended by two $1\frac{3}{8}$-inch close-link chains, rove through two sets of pulley-blocks placed on the top of a pair of shear legs projecting over the stern of the barge. Two

other sets of pulley-blocks are attached to the ends of a cross-head of plate and angle iron, riveted outside the funnel, and connected by strong iron stays to the chamber of the bell. When the bell is hanging in the air each part of the chain sustains (omitting friction) 10 tons, or less than half the Admiralty proof strain; but when the bell is in the water, and full of air, the strain on each part of the chain probably does not exceed 4 tons or 5 tons, even when the trays are quite full of excavated material. The bell-barge is rectangular in plan, 80 feet long, 30 feet wide, and 8 feet deep, with two longitudinal single-webbed girders running fore and aft in the line of the shear legs; these girders are latticed amidships for about half their length, and are plated at the extremities. A quantity of concrete, at the end remote from the bell, balances the weight at the other end, and leaves a safe free-board at the stern when the bell is out of water. A horizontal engine, with a cylinder 8 inches in diameter, and a length of stroke of 18 inches, drives the air-pump, which is a horizontal cylinder, parallel and similar to the steam-cylinder, but 9 inches in diameter, the piston driving the air in place of being driven. The compressed air is cooled when passing through a short metal pipe leading under the deck to the coupling of the flexible hose, and again in the hose and inside of the funnel, as also in the chamber itself, which is kept cool by the surrounding water, so that no annoyance is felt in the bell from overheated air. When the pump is working at its usual rate of thirty-six double strokes per minute, the temperature of the contained air is about 102° F., while that of the air in the bell-chamber varied, in the observations which have been taken, from 50° to 59°, and that of the external atmosphere from 44° to 57½°.

The water-surface inside the chamber is quite calm in all weathers, and when on level ground is only about ½ inch deep, so that it gives a plane surface of 400 square feet, which enables the bottom to be levelled with the greatest facility and accuracy. The funnel has a scale of feet marked on the outside, and acts as a sounding-rod or level-staff; thus the proper depth of excavation is readily obtained by comparing its indication with that of a standard tide-gauge fixed a few yards distant. Nothing can exceed the simplicity and satisfactory way in which this works. A double cylinder engine, each cylinder being 6 inches in diameter, with a length of stroke of 8 inches, actuates two crab-winches on the deck, which hoist the bell. Six men and a ganger work inside the chamber together, four hours at a spell. There are two gangs, and each gang works one spell every second day, and two spells on the

alternate days, averaging six hours' work per day, except on Saturdays, and in winter, when the hours are somewhat shorter. The Author is indebted to the late Mr. George Strype for the design of the horizontal air-pump, and the air-tube passing down the inside of the funnel of the bell. Mr. Strype's analysis of the working of the pump is given in the Appendix (p. 354). The remainder of the machinery and works was designed by the Author. Messrs. Harland & Wolf, of Belfast, were the contractors for the hull, Messrs. Courtney, Stephens & Co., of Dublin, were the contractors for the machinery of the floating shears, and Messrs. Grendon & Co., of Drogheda, were the contractors for the diving-bell and barge. Some portions, however, of the foregoing plant were constructed, and the works now in progress are being executed, by the Author, for the Dublin Port and Docks' Board, without the intervention of a contractor.

Lifting and Setting a Block (Plate 16, Figs. 3 and 4).

The operation of lifting and setting a block is as follows:— The floating shears is brought bow on to the block wharf during the flood tide, and the suspender bars, already in position in one of the large blocks, are attached to the cross heads of the lower set of pulleys. The chains are then hauled in by the crab winches, and the centrifugal pump is started to fill the tank, but as its action is slower than that of the winches the vessel soon dips at the bow a few feet more than at the stern. As soon as this is considered sufficient, hauling in of the chain ceases, and the final lift of the block is done by the quiet action of the water filling the tank, and bringing the vessel on an even keel. So quietly is the operation performed, that a person on board is unconscious, unless he is looking at the block, of the moment when it parts from the wharf. The machinery is quite competent to lift the block off the ground, but the *modus operandi* described has the advantage of not putting so severe a strain on the chain as if it were hauling in when all the weight is on, for the increased strain due to moving friction is thus avoided. The block is grasped on either side by a pair of timber booms hinged near the feet of the fore shear legs, and lowered down like the arms of a man, one on each side of the block, and a diagonal chain and tightening screw to each boom enables them to grasp the block tight, and keep it from swaying from side to side. As the block is hung from a point 53½ feet over the deck there would be a powerful leverage to capsize the vessel if the latter took a serious list. The booms, however, prevent anything of this sort, for if the vessel had a

small list to one side, this list would be removed by causing the boom on that side to bear hard against the block and press it a little over to the other side; or if desired, a list in the opposite direction could be created by pressing the block still further over. The centre of gravity of the block might also from inadvertence not lie exactly midway between the chains, and thus cause a few tons more pressure on one set of chains than the other. This would tend to produce a list of the vessel to that side, but the boom on that side being made to bear hard on the block will move it a little over and bring the centre of gravity to agree with the central line of the vessel. In addition to this, water can be let into either of the fore-side compartments, and 1 ton of water in one compartment will balance an excess of nearly 4 tons on one set of chains over the other. These things are mentioned to show the perfect control which exists in case an error should occur in finding the exact centre of gravity. In practice, however, there has been no difficulty in doing so accurately, by the well-known method of finding the intersection of two plumb lines hanging in front of a model profile of the block, cut out of a thin board of yellow pine to the scale of 1 inch to the foot. As soon as the block is afloat, the vessel is warped a little off from the wharf, and the block lowered in the water to about half its height (depending on the local depth of water), merely to relieve the chains and other parts of the structure by the partial displacement, which amounts to from 80 tons to 100 tons. If lifted in the forenoon, the block is generally laid at low water in the afternoon; if lifted in the afternoon, it is laid at low water the following morning; yet it has occasionally been left hanging on for several days together. As already mentioned, there are powerful surging heads on deck for warping the vessel, but sometimes it is towed to its destination by a tug steamer, which seems desirable when the distance exceeds $\frac{1}{3}$rd of a mile. The vessel is then moored in position, and the block lowered to within a few inches of the bottom, and close to the block previously set. The exact adjustment of the block in place is simply managed, for massive though it may be, yet from the length of the chains it hangs freely like a plumb bob, and can be readily moved within a limited range. The following is the method adopted for bringing it accurately into position. Short timber posts or bollards, about 11 inches square, are temporarily wedged into the grooves in the sides of each block. Two of these bollards are in the block already in place, and two in the block being set in position, all ranging in the length of the wall. On either side of the bollards a short piece of balk timber is placed horizontally, and a couple of screw bolts

clamp these together, and keep all four bollards in range, just as fish plates hold rails in line. This adjusts the range of the blocks, and they are then drawn up into close contact by a small tackle, one end of which is attached to one of the suspender bars, and the other end to one of the blocks previously set. These operations are completed when the block is within 3 inches or 4 inches of the bottom; it is then finally lowered gently into place by pumping water out of the tank. On one or two occasions, when the adjustment was not quite correct, the block was lifted again for a few minutes, readjusted, and again lowered into place. The control over it is so complete, that if there were any object in doing so, it would be quite possible, after a number of blocks have been set in place, to lift them one after the other, and put them back on the block wharf again. The average width of each joint, obtained by measuring a length of more than 300 feet of the wall, is only $\frac{3}{5}$ths of an inch—a proof of the accuracy with which the blocks are laid in place. As already explained, this opening is subsequently plugged by the concrete dowel, between block and block. The two following tables give the cost of the work :—

Table 1.

Cost of Plant.

	£
Diving bell and barge,	5,454
Floating shears,	18,783
Block wharf,	4,610
Cranes, concrete mixer and engine, chain-testing machine, rails, lorries, weighbridges, panels for blocks, moorings, stone barge, &c.	5,000
	£33,847

Table 2.

Cost of Quay Wall per foot run.

	£	s.	d.
Excavating and levelling foundations with bell, including maintenance of bell and bell barge,	3	0	0
Block standing on the wharf, including erection and maintenance of panels, casing of tubes for suspender bars, girders and masonry,	16	0	0
Lifting and setting block, including maintenance of floating shears,	2	10	0
Filling side grooves with concrete,	0	10	0
Superstructure above block, faced and coped with granite ashlar,	11	2	0
Shifting the moorings, maintenance of wharf and sundries,	1	0	0
	£34	2	0
Interest on plant at 7 per cent., supposing 400 feet per annum laid,	5	18	6
Cost of wall, 43 feet high, complete, per foot run,	£40	0	6

The total cost of the wall is in round numbers £40 per lineal foot, or less than one-half what it would be if built in the usual manner inside a cofferdam with double sides in a depth of 40 feet of water, including the expenses of pumping, and the consequent saving has already much more than paid for the whole cost of the special plant. It should be borne in mind, that Portland cement is about 20 per cent. dearer in Dublin than in London; that stone and labour are much more expensive in Dublin than in the country parts of Ireland; and that wages and materials of all kinds are far dearer than they were a few years since. The progress of the work depends chiefly on the rate at which the divers can prepare the foundations. When the depth of cutting is 4 feet, each block 12 feet in length requires $46\frac{1}{4}$ cubic yards of excavation, and when, as has hitherto been the case, the ground is tenacious clay, the preparation and levelling of the foundation for each block occupy sixty-two hours, or an average week's work for two gangs of men working in spells, each gang consisting of six men digging and one ganger directing, or seven men in the bell at one time. This is equivalent to $\frac{3}{4}$ cubic yard of tough clay excavated per hour, which may appear a small quantity; but about one-sixth of the whole time is spent in discharging the trays and spelling the gangs; and a considerable, but indeterminate time is required for levelling the bottom accurately, as the men cannot excavate so boldly when within a few inches of the final depth as at a higher level. The cost of the bell-work, including maintenance, but not interest on plant, is about 15*s.* per cubic yard of excavation. The necessity of accurately levelling the ground, as already explained, and the tenacious character of the clay, make this item of expense greater than it would be in a rougher kind of work or in freer ground. Allowing for the time spent in repairs and painting, the special plant in Dublin is sufficient to lay from 500 to 600 lineal feet of quay per annum; but the rate of progress for the first two years was only 300 feet each year; first, because at the commencement of such a novel work it was deemed prudent to proceed gradually; and, secondly, because the bell was engaged for several months each year in another part of the harbour, drawing the stumps of piles which had been broken off at a depth of from 15 feet to 20 feet below low water. In this operation it proved exceedingly useful: the men first excavated round the head of each stump to get room for grasping it with one end of a chain, the other end of which was fastened to a powerful ring bolt in the roof of the bell, and when the latter was lifted by the engine on board the barge, it readily drew up several stumps at one

time. If the floating shears alone were required, say for a breakwater, where accurate levelling of the ground and nice adjustment of the blocks are unnecessary, the progress of the work would depend on the weather. Supposing two days on an average were spent in depositing each block, and there were only two hundred sufficiently fine working days per annum, a length of from 1,000 to 1,200 lineal feet of blocks could be laid with one floating shears each year. Of course, in extensive works such as harbours of refuge, several floating shears might be used at the same time, and thus expedite the work. The weather does not interfere with the bell-work, and seldom with the lifting of a block; but it is not desirable to move about the floating shears on a stormy day, especially if vessels happen to be lying in its course.

Concrete Beacon.

The Author constructed an 80-ton block of concrete in the years 1863–4, and carried it between a pair of iron lighters about 2 miles down the river, where it now forms the base of a beacon tower for marking the navigable channel. This was at the time probably the largest block of concrete that had been moved in this manner. The beacon was required near the side of the river, in a depth of $5\frac{1}{2}$ feet at low water of spring tides, and as the money to be spent was limited—for it was to compete in cost with a timber beacon—it was obviously impossible to make a coffer-dam, or adopt any plan entailing costly temporary works. The base of the tower was a ring of 19 feet external and 9 feet internal diameter, the thickness at the base being 5 feet, with a batter on the outside of 1 inch in the foot. The height of the ring was 6 feet 2 inches, and its weight slightly exceeded 80 tons. This was built on a platform of 3-inch planks laid on the strand, which was dry at low water, in the vicinity of the block wharf. Four small cast-iron washers, having a bearing area of 1·5 square foot each, were built into the base, and vertical tubes were left in the ring over each washer, in the same way as already explained in the large blocks. When the ring was consolidated, two iron mud barges, belonging to the dredging department, were placed one on either side about 20 feet apart, and balks of timber were laid across their decks spanning the intervening space where the ring lay. Four suspender-bars of 2-inch round iron, with screwed ends above and T ends below, were then lowered between the balks into the tubes formed in the concrete, and the bars were turned at right angles so that their T ends caught below; the nuts above were

then screwed down over iron plates which rested on the balks, and the whole was floated off as the tide rose, and carried down the river. At low water the ring took the ground, the nuts were unscrewed, the suspender-bars were withdrawn, and the barges went back to their regular work. A few days after the ring had been set in place it was found that some of the planks on which it had been built, and which had been merely laid as a platform on the strand, adhered to the bottom, and prevented excavation within. Accordingly the barges were sent down to lift the block as before, and when this was afloat, a few blows with a pole knocked away the planks, and the ring was again set in place. This annular wall was raised several feet with concrete, and shortly after the operation of sinking commenced, as described in a diary kept by Mr. Conolly, the chief foreman of works:—

"1864. *June* 10th.—Three hand-pumps, 11 feet long and 4 inches bore, set to work and lowered water in well 8 feet, or within 2 feet of the bottom, when the water burst in from beneath and overpowered the pumps. Put some clay round outside of base.

"*June* 20th.—Three pumps set to work and drained out well in one hour; after that one pump sufficed until the tide rose over the top of the ring; in 3½ hours excavated 18 inches deep and 2 feet 6 inches underneath ring: ring sank 8 inches on south and 4 inches on north sides; ground full of shells with a small quantity of pebbles.

"*June* 21st.—Repeated same operations as yesterday, but worked only two hours in well; sea very rough; ring sank 10 inches and quite level; total sinking 1 foot 4 inches. Sand came into excavation equally all round and more uniformly than yesterday.

"*June* 22nd.—Three and a half hours' work; sank 9 inches quite level; total sinking 2 feet 1 inch.

"*June* 23rd.—Same operations repeated, 3½ hours' work; average sinking 9 inches, most on east side; total 2 feet 10 inches.

"*June* 24th.—Three and a half hours' work; ring sank 10 inches and very level; total sinking 3 feet 8 inches.

"*June* 25th.—Three and a half hours' work, sank 6 inches; total 4 feet 2 inches. Bottom very fine woolly sand.

"*June* 27th and 28th.—Raised top of ring 4 feet 2 inches with concrete; total height 14 feet 6 inches.

"*June* 30th.—Lengthened three hand-pumps to 15 feet; dried out well in 1½ hour, got a quantity of excavation out, and the tower sank 5 inches, when the bottom burst in at N.E. point, where the clay outside had been wasted by the heavy wash of the sea. A quantity of clay was forced under the foundation and into the well by the rush of water.

"*July* 2nd.—Got 120 tons of clay put round base of tower; total clay used 305 tons.

"*July* 4th.—Pumped out well in 2½ hours; 3 feet of sand and clay in well from burst of 30th ult.; got it and a quantity of the bottom out. Leakage greater than on any previous day: tower sunk 4 inches; total 4 feet 10 inches.

"*July* 5th.—Pumped out well in 1½ hour; finished excavation and tower sunk to final level, 5 feet under surface of ground and about 10 feet 6 inches below low water zero."

The superstructure was then completed at intervals in eight working days. The height of the concrete tower is 38 feet. It is surmounted by a timber beacon, 6 feet high, fixed on a short mast 3 feet high, making the total height 47 feet, the elevation over high-water level being about 24 feet. The core of the tower is filled with ballast, which, as well as the clay, was dredged in the harbour. The cost was under £200, exclusive of payment for the use of the barges.

Concrete Mixer (Plate 15, Figs. 8, 9).

The method adopted by the Author for making both concrete and mortar differs in several respects from the custom elsewhere. The gravel or sand, according as concrete or mortar is required, is tipped from barrows into large rectangular trays of rough deals without ends, generally of the following dimensions: length 20 feet, breadth 6 feet to 8 feet, height of sides 2 feet to 4 feet. As soon as the tray is filled with ballast, a straight edge is passed along the top to strike the ballast to a uniform level with the top of the tray, and battens of a definite thickness are then laid on the top to gauge the due proportion of cement, which is spread evenly over the ballast, its surface being levelled with the straight edge as before to coincide with the upper surface of the battens. Thus, if the tray be 3 feet high and the battens 6 inches deep, the proportion will be 6 of ballast to 1 of cement; if the battens be 4½ inches deep, 8 of ballast to 1 of cement, and so on. Two men to each tray then shovel the dry material into the mixer, pushing their shovels along the floor of the tray, whereby the cement sheds itself uniformly down the slope of the gravel and becomes mixed with it to a certain degree.

The mixer is an open trough of cast or wrought-iron, from 7 feet to 9 feet long, and 3½ feet wide. The lower half is semi-circular, and the top sides are slightly splayed out. A wrought-iron shaft, 3½ inches square, with wrought-iron blades, passes through the centre of the trough, the blades being arranged to

screw the concrete forward as the shaft revolves. The pitch of the blades can be adjusted at will by turning them more or less in their sockets, and the travelling movement is accelerated by inclining the trough in the direction of its length, so that it may have a fall towards the delivery end. The motion may be communicated either by a belt or gearing from an engine of 2 HP. or 3 HP. The method of working is as follows:—The gravel and cement, in their proper proportions, are shovelled from the tray alongside directly, without hand-mixing, into the upper end of the trough, where the first three or four blades toss over and incorporate the dry ingredients thoroughly. They then pass under the water-rose, about one-third of the length of the trough from the upper end, and from thence to the delivery end the mixture of gravel, cement, and water is perfected, and the mortar or concrete comes out quite uniform in colour and homogeneous in quality. The machinery is of the simplest character; all the operations are open to view, and the friction and consequent useless expenditure of labour are reduced to a minimum; and large stones pass through it which would destroy any ordinary mortar mill. After several months the ends of the blades become shortened by wear, a small interval being left between them and the lower half of the trough; the latter gets coated with hard set mortar forming a lining to the trough, and when the blades are lengthened again, which is done by simply welding a scrap of iron or steel to their ends, the coating of mortar is chipped off, and the machine restored to its original condition. The great advantage of this machine over hand labour consists in the facility it affords for mixing the ingredients thoroughly and with a small quantity of water. It never flags, and requires little attention, whereas labourers are apt to add an excess of water to relieve the toil of turning over a stiff mass, or they add water in irregular quantities, and rarely incorporate the principal ingredients in a thorough and uniform manner. As already stated, this concrete mixer is equally efficient for making mortar. Indeed, the Author thinks it preferable to any mortar mill with which he is acquainted, especially the pan with edge-runners, which tend to grind and triturate the sand, thus reducing its sharpness, and doing useless work. In the manufacture of hydraulic mortar the proper mode of proceeding seems to be: First, to have the cement or lime reduced to a state of fine powder. Secondly, to incorporate the sand with the cement or lime in the dry state. Thirdly, to temper the mixed ingredients rapidly with a moderate amount of water let on gradually as required. When lime is not ground, and when, therefore, lumps

occur in it, the edge-runners doubtless crush them, and thus render the mortar homogeneous. In this respect only does the pan mill seem to present any advantage over the mixer just described. The latter is far simpler, cheaper, and more rapid in its operation, a single mixer when well attended being able to turn out from 8 cubic yards to 10 cubic yards of concrete or mortar per hour with thirty revolutions of the shaft per minute; that is to say, one mixer driven by a 3 HP. engine will make as much mortar as twelve ordinary pan mills, while its cost is only from £30 to £35, and it can be set up anywhere on a couple of wooden trestles.

This machine has also been applied to pulping peat; and if a fire were placed beneath, it might be successfully used for pulverising and dessication, as, for example, drying and pulverising sewage mud or similar matters.

Breakwaters.

The Author has now described some of the works on which he has been engaged, but it is evident that the new method of building with large blocks is of much wider application. Its advantages will probably be more marked in the construction of piers and breakwaters, such as those of harbours of refuge, which have hitherto been a frequent source of anxiety and expense. Stone breakwaters may be divided into six classes:— Breakwaters built of rubble stone on the long slope principle, either with a paved sea face like those at Plymouth, Howth, and Kingstown harbours, or with a rough sea face formed of large rubble laid at random. Breakwaters formed of artificial blocks of from 10 cubic metres to 20 cubic metres each, laid promiscuously at an angle of about 45°, as at Alexandria, Leghorn, Algiers, Marseilles, and other French harbours, the mound being sometimes composed entirely of artificial blocks, though generally the hearting and lower part are formed of rubble with the large blocks on the sea face, the breakwater being surmounted by a roadway and parapet wall of masonry. Breakwaters like those at Cherbourg, Holyhead, and the Tyne, constructed of a mound of rubble reaching from the bottom of the sea to a little over low-water level, along the axis of which is a vertical wall or backbone of masonry, the foundations being laid in the heart of the rubble at extreme low-water level. Breakwaters like that at Alderney, which resemble the last class, with the exception that the base of the masonry backbone is laid by divers several feet below low water. The breakwater at Kurrachee

harbour may be included in this class, as the 27-ton concrete blocks of which its superstructure is formed are laid regularly, though they are not bonded together with mortar. Breakwaters of loose rubble stone held together by a cribwork of timber, as at Blyth. And, finally, breakwaters built regularly with ashlar stone or artificial blocks from the bottom of the sea vertically upwards, like the Admiralty pier at Dover.

The two systems chiefly in favour in the United Kingdom, namely, the long-slope system with paved sea face, and that in which a masonry backbone is founded on the axis of a rubble mound at low-water level, both contain the elements of destruction within themselves, unless in the one case the base of the paved slope, and in the other the base of the masonry backbone, is protected from being ripped up or undermined by the waves. When this protection is wanting, an apparently slight injury at the base eats upwards like a canker, and spreads rapidly over a large area; and unless prompt measures are taken to replace the lower courses where the mischief generally begins, and to protect them as best may be against a similar recurrence, the destruction of the superstructure of the breakwater is only a question of time. Plymouth, Sunderland, Kingstown, Howth, Tynemouth and Holyhead breakwaters have been long enough in existence to show how the evil acts. The rubble mound protecting the lower courses of the paved slope, or the base of the masonry backbone, large as its constituent stones may have been originally, is yet not massive enough to resist the action of heavy storms, and the stones are knocked about and worn away gradually till they lose their original shape and volume, and change from sharply quarried blocks into rounded boulders. These in turn are constantly rolled about till they are reduced to gravel, which, in some instances at least, is swept round the pier-heads, and forms a dangerous shoal at the entrance of the harbour, involving the necessity of employing dredging machinery to remove the débris of what a few years previously formed an integral portion of a structure apparently destined to last for ages. The same destruction sooner or later seems destined to await the breakwater formed with a long slope of rough rubble stone, unless indeed its sea face be coated with artificial blocks of sufficient size to resist the action of the sea; for though the larger blocks of natural stone may apparently resist the waves for a time, every unusually severe storm makes a greater or less change in their contour, and the stones are gradually reduced in bulk, and ultimately washed over the crest or round the end of the breakwater, which will thus in process of time more

and more approximate to the condition of a shoal. It is instructive to observe the wave-like shapes that the rubble foreshore outside a vertical wall assumes. In some parts it is piled up so that the crest of the stone wave reaches high up on the masonry, or even outtops it, in which case the stones are washed over into the harbour; in others, the hollow of the wave approaches the base of the wall, and when it goes below it, the local destruction of the latter is inevitable. After another storm the stone waves will have moved forwards, and their crests and hollows have changed places, and in time this travelling motion will generally bring a large portion of the foreshore, so far down as the action of the sea is sensible, round the pier-head as already described; though in the case of one pier under the Author's charge the travel is towards the land, and the pier-head is being rapidly stripped of its former protection. The remedy for this evil is expensive, still it seems the only one, for merely mending the breaches by throwing down fresh material of the same size as that removed by the waves is but a temporary expedient. Large artificial blocks appear to be the only final remedy, and these must be of such a size that they will not travel. The smaller stuff below and around them may be washed away, and the blocks themselves may subside locally until their base is below the level at which the waves will act on the foreshore, but when once they have reached this level further derangement need not be apprehended. Some apology may be considered due for thus freely criticising the designs of the great men of a past generation, but no apology is really required. They acted up to their lights, and according to the state of mechanical knowledge in their day; and engineers of the present day would be most unworthy successors of those eminent men if they were not to benefit by their practice, and derive that experience from their works which time alone can give.

The vertical wall, of which the Admiralty pier at Dover has been selected as the type, is free from the special sources of destruction to which the long slope or the wall with rubble foreshore are liable. Its base is laid below the disturbing action of the waves, and, if the foundations are secure, and if the individual stones are massive enough, or so bonded together that they cannot be disturbed by the action of storms, the upright wall seems to possess the desired elements of stability and durability. The cost, however, of the vertical breakwater is usually great, and its progress slow, two things which seem to have interfered with its general adoption. The Author submits that both these objections may in most localities be removed by the new method of construction.

There may be several days in the year during which a block could not be set in exposed situations; but, supposing there are only one hundred and fifty suitable working days in each year, the rate of progress, even with but one floating shears, will exceed that of the ordinary method; and in works of such magnitude as harbours of refuge there is no reason why several such appliances should not be used simultaneously. When the depth at low water exceeds 30 feet to 40 feet, it may be desirable to use two blocks one above the other, or to raise the foundation by a mound of rubble stone extending to within 25 feet or 30 feet of low water; that is, to a depth below that at which the action of the waves is sufficient to move the stones forming the mound. A single, double, or triple row of blocks might be laid on the axis of such a mound after it has been allowed to consolidate, and even supposing that local settlement of the mound takes place, this will not affect the cohesion of individual blocks, nor will it in any way injure the adjoining blocks; and if a wide roadway is required on the top of the breakwater, rubble filling can be thrown in between a double row of blocks so as to obtain any desired width of pier.

The Paper is illustrated by a series of drawings and diagrams, from which Plates 15 and 16 have been compiled.

APPENDIX.

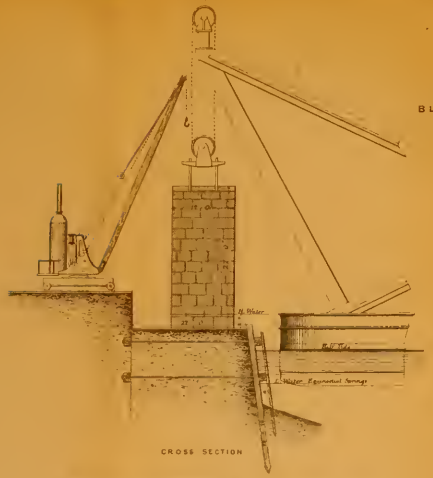
Analysis of the Air-Pump on board the Bell Barge.

Pump, 8 inches in diameter, length of stroke, 18 inches; double acting. Ports, $3\frac{1}{2}$ inches by $\frac{7}{8}$ inch. Valve, $2\frac{1}{2}$ inches stroke, $\frac{3}{8}$ inch cover on exhaust side, and $\frac{1}{2}$-inch on discharge side. Clearance of piston at the end of the stroke, $\frac{1}{2}$ inch, making with the contents of the port a space equal to 1 inch at the end of the cylinder. Since 35 cubic feet of salt water weigh 1 ton, $\frac{35 \times 144}{2240} = 2\frac{1}{4}$ feet of depth = 1 lb. per inch. The minimum depth of water to work in is assumed to be 25 feet, and $\frac{25}{2\frac{1}{4}} = 11$ lbs. per inch. The maximum working depth is 38 feet, and $\frac{38}{2\frac{1}{4}} = 17$ lbs. per inch. Assume that $\frac{1}{2}$ lb. per inch is absorbed by the friction of the air through the port, then $15 - \frac{1}{2} = 14\frac{1}{2}$ lbs. per inch, which will be the pressure on the suction side with every depth of water so long as the valve is open. With 25-feet depth of water the pressure on the discharge side will be $15 + 11 + \frac{1}{2} = 26\frac{1}{2}$ lbs. per inch so long as the valve is open. With 38-feet depth the pressure on the discharge side will be $15 + 17 + \frac{1}{2} = 32\frac{1}{2}$ lbs. per inch while the valve remains open, atmospheric pressure in each case being included.

CONSTRUCTION OF MARINE WORKS

WITH ARTIFICIAL BLOCKS OF LARGE SIZE

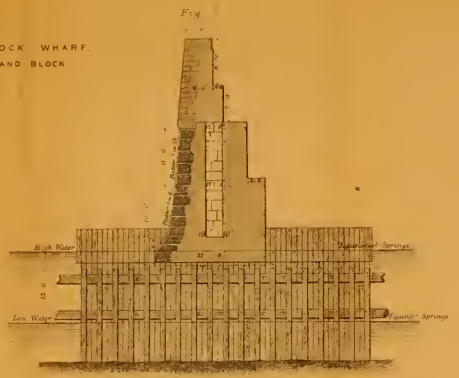
Fig 1



CROSS SECTION

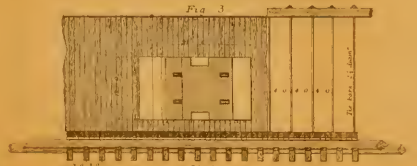
Fig 2

BLOCK WHARF AND BLOCK



FRONT ELEVATION

Fig 3

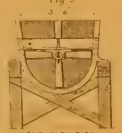


PLAN

Fig 4 CONCRETE OR MORTAR MACHINE

PLAN

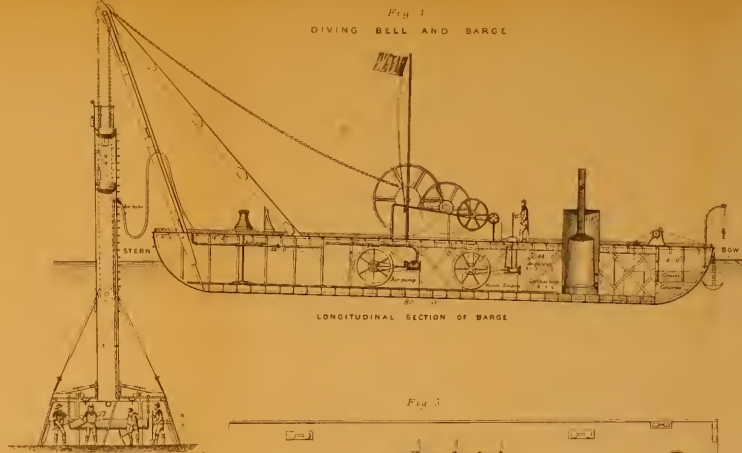
Fig 5



END ELEVATION

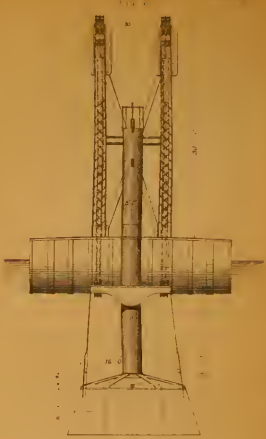
Fig 1

DIVING BELL AND BARGE



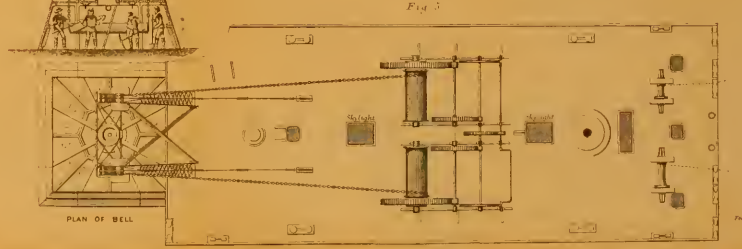
LONGITUDINAL SECTION OF BARGE

Fig 2



END ELEVATION

Fig 3



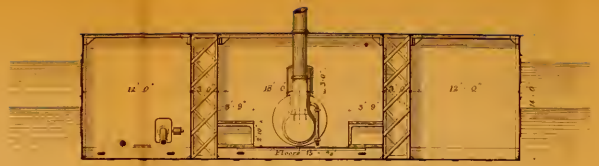
PLAN OF BELL

PLAN OF BARGE

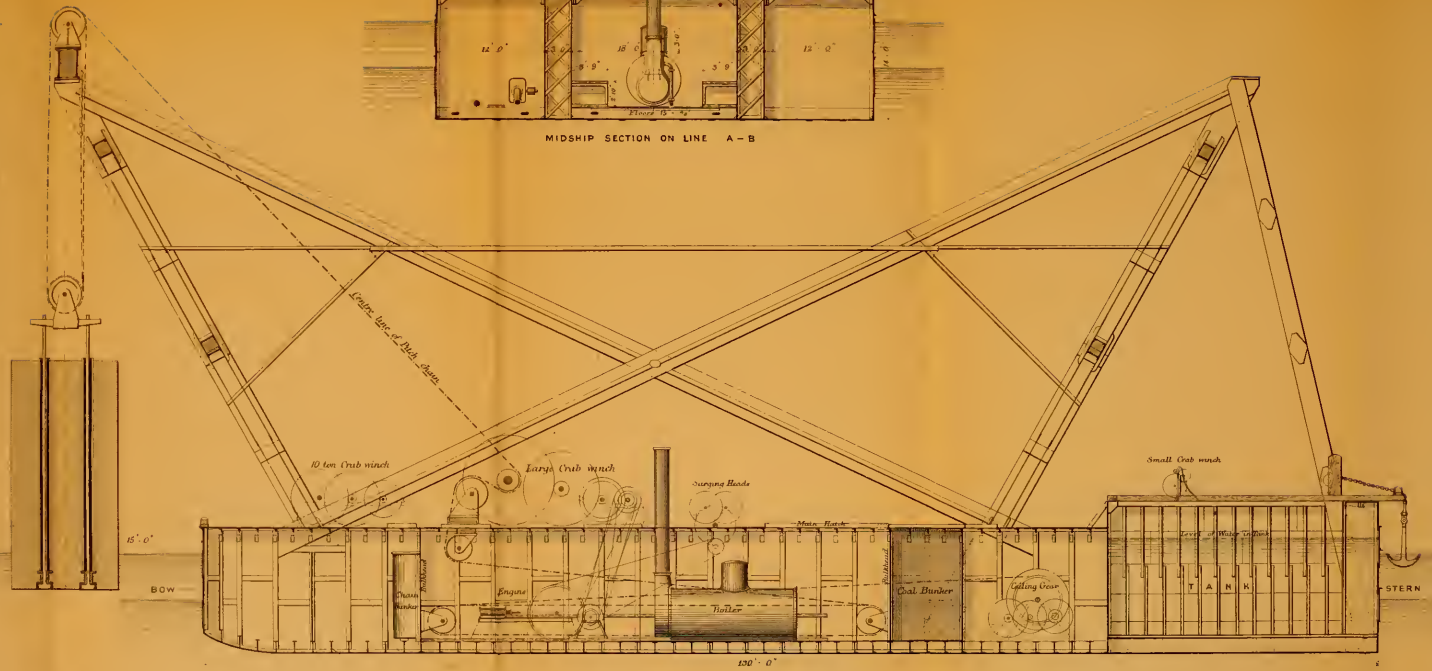
Fig 4

MIDSHIP SECTION OF BARGE

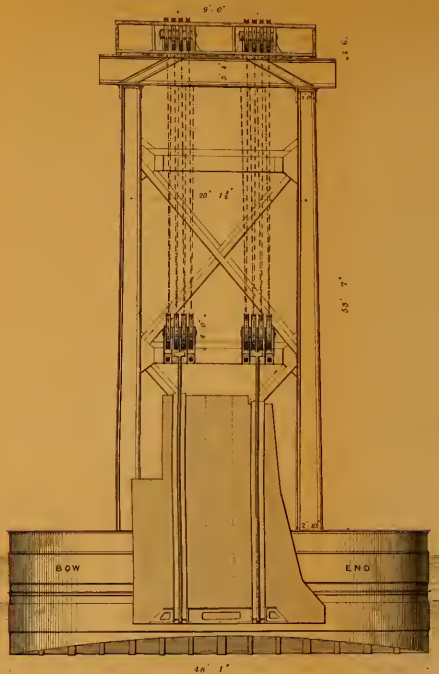
FLOATING SHEARS.



MIDSHIP SECTION ON LINE A – B



LONGITUDINAL SECTION SHEWING ARRANGEMENT OF MACHINERY.



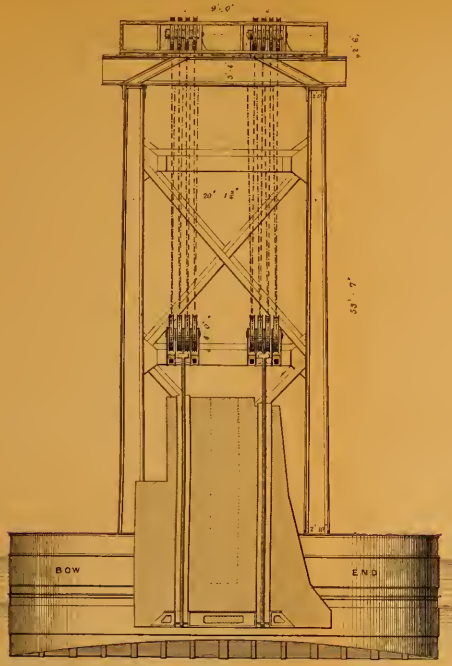
END ELEVATION

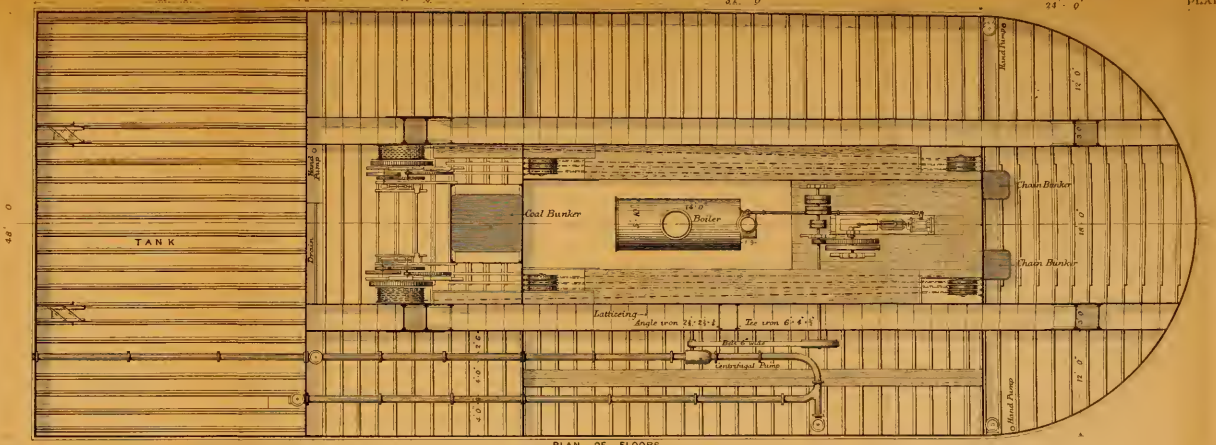
Scale.
Feet 10 0 10 20 30 40 50 Feet

CONSTRUCTION OF MARINE WORKS,

WITH ARTIFICIAL BLOCKS OF LARGE SIZE

FLOATING SHEARS.





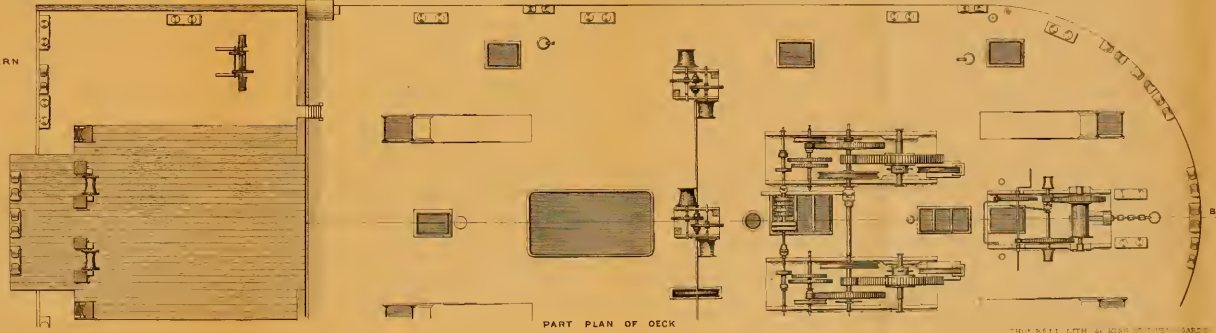


PLATE 16

The following Table gives the pressures on both sides of the piston at various points of the stroke.

Degrees passed through by the crank.	Space passed through by the piston from beginning of stroke.	Degrees moved through by the eccentric from the middle of its stroke.	Space moved through by the valve from the middle point of its stroke.	Port open for exhaustion.	Port open for discharge.	25 feet depth of water.		38 feet depth of water.	
						Pressure of air on suction side, atmosphere included.	Pressure of air on the discharge side, atmosphere included.	Pressure of air on the suction side, atmosphere included.	Pressure of air on the discharge side, atmosphere included.
°	inches.	°		inch.	inch.	lbs.	lbs.	lbs.	lbs.
0	0	—20	—·43	0·05	0	28·0	15·0	34·3	15·0
5	·04	—15	—·32	0	0	27·0	15·0	33·0	15·0
10	·14	—10	—·22	0	0	24·6	15·1	30·1	15·1
15	·31	— 5	—·11	0	0	21·4	15·2	26·3	15·2
20	·54	0	0	0	0	18·2	15·4	22·3	15·4
25	·85	5	·11	0	0	15·1	15·7	18·5	15·7
30	1·21	10	·22	0	0	*12·7	16·0	15·5	16·0
35	1·64	15	·32	0	0	*10·6	16·4	*13·0	16·4
40	2·10	20	·43	·05	0	13·5	16·9	14·0	16·9
50	3·21	30	·62	·25	·12	14·5	*18·0	14·5	*18·0
60	4·50	40	·80	·43	·30	14·5	*19·7	14·5	*19·7
70	5·92	50	·96	·58	·46	14·5	*21·8	14·5	*21·8
80	7·44	60	1·08	·71	·58	14·5	*24·6	14·5	*24·6
90	9·00	70	1·17	·80	·67	14·5	26·5	14·5	*28·5
100	10·56	80	1·23	·86	·73	14·5	26·5	14·5	32·5
110	12·08	90	1·25	·88	·75	14·5	26·5	14·5	32·5
120	13·50	80	1·23	·86	·73	14·5	26·5	14·5	32·5
130	14·79	70	1·17	·80	·67	14·5	26·5	14·5	32·5
140	15·90	60	1·08	·71	·58	14·5	26·5	14·5	32·5
150	16·79	50	·96	·58	·46	14·5	26·5	14·5	32·5
155	17·15	45	·88	·50	·38	14·5	26·5	14·5	32·5
160	17·46	40	·80	·43	·30	14·5	26·5	14·5	32·5
165	17·69	35	·72	·34	·22	14·6	26·5	14·6	32·5
170	17·86	30	·62	·25	·12	14·8	26·5	14·8	32·5
175	17·96	25	·53	·15	·03	15·0	27·0	15·0	33·0
180	18·00	20	·43	·05	0	15·0	28·0	15·0	34·3

Note on the above Table.—On the suction side, before the valve opens, the pressure falls below the atmospheric pressure. See the pressures marked * in the suction columns.

On the delivery side, as soon as the valve opens, the air will re-enter the pump from the diving bell until, by further compression, the pressure equals that in the bell. See the pressures marked * in the discharge columns. Thus the valve opens late for the suction side and too early for the discharge side. These are weak points in the system, but it is presumed that other good points will more than compensate for them. This system, however, cannot be carried to much greater pressures without serious loss.

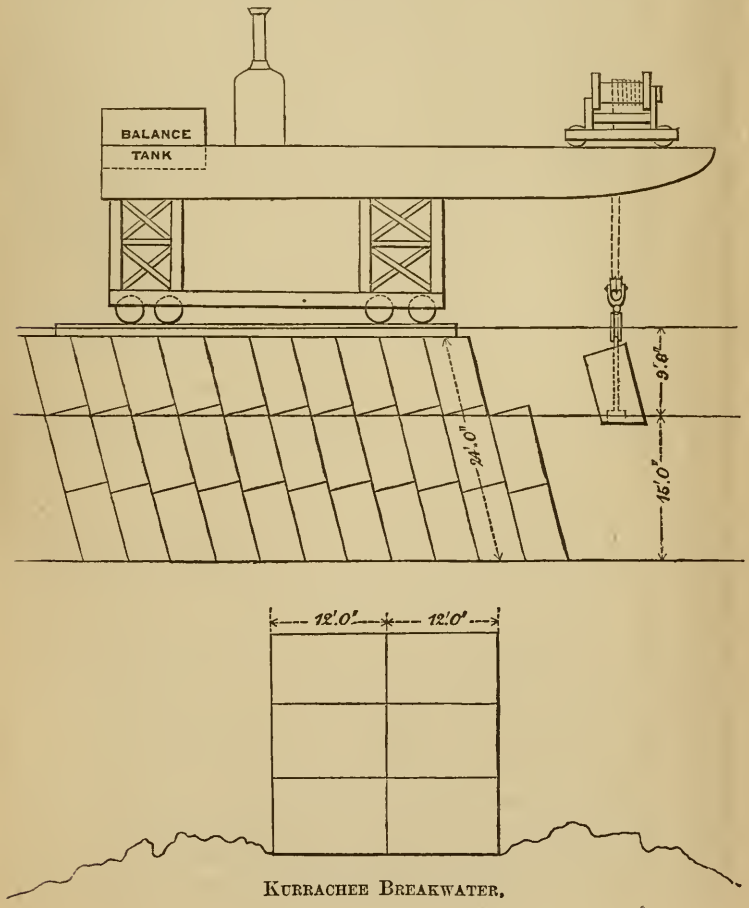
Mr. Abernethy observed that several years ago he visited the harbour works at Dublin, and was exceedingly interested in them. Mr. Stoney might be regarded as the pioneer in constructing hydraulic works with large masses of concrete. Not only had he been successful in carrying out this work, but he had shown great ingenuity in designing the requisite machinery. The latter part of the Paper contained some useful comments upon the construction of the various breakwaters of this country. On a former occasion, Sir John Coode stated[1] that one cause of the destruction of the superstructure of the breakwater at Alderney was owing to the long slope formed by the rubble mound converting the wave of oscillation into a wave of translation, and the constant percussive action of the sea upon the mound tended to destroy and to undermine the superstructure. That was the case no doubt at Alderney; and, inasmuch as the breakwaters at Holyhead and at Portland were constructed in almost precisely the same way, the only difference being that the foundations of the superstructure were more or less laid below the level of low water, he apprehended Mr. Stoney's anticipations would prove correct, and that the gradual action of the sea upon the rubble mound would convert the masses of stone into boulders, and gradually into a shingly beach. The only way to preserve those breakwaters would be, as suggested, to throw upon the seaward face large masses of concrete. He thought in future engineers should give more attention to the construction of breakwaters with vertical walls. Mr. Stoney had to a great extent solved the difficulties which had hitherto attended that mode of construction, such as the length of time occupied, and the great expense involved.

Mr. Parkes observed that the conception was a bold one, and it had been carried out with great skill. The designs were original, and almost every detail was worthy of study. The concrete mixer was an excellent contrivance, and he should prefer it to those which he had used, if it were not that the latter produced an almost perfect concrete. He had used Mr. Messent's mixer at Kurrachee, and it certainly appeared to leave nothing to be desired. Mr. Stoney's, though different, seemed to possess similar advantages. Where so much ability had been displayed, and with such great success, it might be considered ungracious to take exception to anything; but he thought it was a matter of doubt whether the principle of using very large blocks in the construction of quay walls and breakwaters should be

[1] *Ante*, p. 92.

accepted as the best. If the object simply was to build a quay wall with blocks of 350 tons weight, then the plan was no doubt a good one; but he did not think such large blocks were in most cases desirable. When no land communication existed between the place where the concrete blocks were made, and the spot in which they were to be deposited, it might be advisable to use them; otherwise he was convinced equally good results might be attained with a considerably less expenditure than this method involved. In order to show upon what this opinion was founded, he would give some particulars of the expenditure on the work connected with the breakwater at Kurrachee which had

FIG. 1.



KURRACHEE BREAKWATER.

been recently completed. The floating shears at Dublin cost £18,783. The plant at Kurrachee, which served the same purpose as the floating shears, consisted of a "Goliath" for lifting the blocks on to the trucks, which cost £660, a "Titan" setting machine, £1,975, a locomotive engine, £1,407, ten trucks of special design, £1,140,—in each case inclusive of the cost of delivery on board ship, omitting the freight,—the cost of erection on the ground was £807, and of extra heavy rails required for the unusual weight of the blocks, £300, total £6,289 as against £18,783. The blocks measured 12 feet by 8 feet by 4 feet 6 inches, and weighed 27 tons each. The next item in the list was the block wharfs, 461 feet long, which probably would contain blocks sufficient for about 350 lineal feet of wall. At Kurrachee, as there was no necessity for having deep water alongside, the block ground was a much more simple affair, and the cost of preparing it for a length of 400 lineal feet of breakwater was £3,000, effecting a saving of £1,600; so that upon those two items there was at Kurrachee a saving, as compared with the Dublin system, of £14,000 in plant. Then taking the cost of the work, the figures at Dublin were, "block standing on the wharf, including erection and maintenance of panels, casing of tubes for suspender bars, girders and masonry, £16 per lineal foot." That was precisely the same as the cost of the concrete blocks for a lineal foot of breakwater at Kurrachee, but the lineal foot contained more cubical contents at Kurrachee than at Dublin, 552 cubic feet as compared with 437, and of course if the circumstances were the same as at Dublin the section might be made the same. The cost at Kurrachee for concrete per cubic yard was 15*s.*; at Dublin it was 21*s.* Probably the difference was to some extent due to the facing of masonry, which no doubt there had been good reason for adopting. Then Mr. Stoney was obliged to introduce into the large blocks two cast-iron girders of 11 cwt. each, in order to take the bearing of the suspending bars, and that would add about £1 per lineal foot to the cost of the wall. The same end was served at Kurrachee by a couple of pieces of hard wood, which had answered every purpose for lifting the smaller blocks. The wood came to 3*s.* per block, or 4*s.* per lineal foot of breakwater, so that upon that score there was a saving of 16*s.* per lineal foot. This seemed a small matter, but it was important in considering the next item. The cost of lifting and setting a block, including maintenance of floating shears, was £2 10*s.* per lineal foot, making, with the 16*s.* remaining over from the last item, £3 6*s.* Now the actual cost of setting the blocks at Kurrachee per lineal foot was £3 9*s.*, giving an advantage of 3*s.* per lineal

foot to the Dublin plan, but that advantage was gained by an extra first cost in plant of £14,000, and would be more than balanced by putting in a portion of another item, the parallel of which at Kurrachee was included in the £3 9*s.*—"shifting the moorings, maintenance of wharf, and sundries, £1." There was no such item at Kurrachee, and a portion of that ought to be added to the £2 10*s.* The item of 10*s.* for "filling side grooves with concrete" was omitted as not being applicable to breakwater work. It was, therefore, evident, even without taking into consideration the extra cost of work of this kind in India over what it would be in Dublin, that there was no advantage in the use of these very large blocks, but that there was the positive disadvantage of a much larger expenditure in the first cost of the plant. With regard to the question of rapidity of execution, he also thought no advantage was to be gained by the use of such large blocks, except possibly where land communication could not be had. Each block at Kurrachee weighed 27 tons, and represented about 9 inches length of breakwater. During the four months, November, December 1872, January and February 1873, a length of 710 feet of breakwater was constructed. In that time there was probably less interruption than there would be in England during any four months of the year, but they were the only four months during which operations could be advantageously carried on there. The actual work done in an uninterrupted day, taking the average of three months when there was no material interruption in any way, was ten blocks, and he believed that that rate could be maintained. Ten blocks per day represented 7½ lineal feet of breakwater; and on the basis of two hundred working days in the year, that would give 1,500 feet per annum; but the Author only claimed from 1,000 feet to 1,200 feet as what could be done upon his system. Probably the higher estimate might be safely adopted, and Mr. Parkes would not have questioned one still higher. He might state, however, that the rate of ten blocks per day was by no means the limit of the capacity of the "Titan," for nineteen blocks had been set in one day, and on one occasion six blocks in an hour and forty minutes, being at the rate of thirty-six blocks in a day of ten hours. Delay was always caused either by the diving work or by the blocks not being brought up fast enough, both of which operations might be accelerated by an increase of force. At low tide the depth of water was 15 feet. He believed that 1,500 feet per annum was within the mark, and that when the staff got into full work the rate would be greater, for every year at Kurrachee the rate had materially increased. The plant used at Kurrachee was

only applicable where there was land communication, but the places in which such communication could not be obtained were few. Detached breakwaters had from time to time been proposed, but such schemes were seldom carried out, as breakwaters starting from the shore were generally preferred. Where, however, water communication was the only one possible, it was probable that a plan like the Author's, with, possibly, some modification of the mode of attaching the block when it had to be carried out to the sea into rather troubled water, might be advantageously employed. At Suez the quay walls were built of blocks nearly of the same size as those at Kurrachee. They were carried to their place on barges, but the rate of work was considerably slower than at Kurrachee. It was impossible to make a satisfactory comparison between the foundation in Dublin harbour and that at Kurrachee. At the latter place the bottom was sandy from 25 feet to 30 feet below low water, in the part to which he had been referring. Rubble stone was dropped from boats, and was levelled by divers. The cost of levelling was about 23*s.* per lineal foot, where the work was carried out as it ought to be. Nearer the shore, where an excess of stone was thrown in, and the amount of excavation was greater, it was more expensive, and in one season was £2 15*s.* per lineal foot. In that case the work was assisted by the steam dredger, which excavated a trench for the blocks. The bottom of this trench was afterwards levelled by divers. In some parts the trench was nearly 6 feet deep; but this was more than he had intended. The cost for excavation in Dublin Harbour was £3. He hoped some explanation would be given of that item, for, considering the excellent contrivance for getting at the bottom, he imagined it might have been done at a cheaper rate; but as he was not acquainted with the circumstances, he did not feel justified in saying the cost was greater than it ought to have been.

Mr. C. B. Lane considered Mr. Stoney's invention a stride in the direction of the economical construction of engineering works in deep water. He would confine his observations to bridge piers. The introduction would doubtless be recollected of Dr. Potts' pneumatic principle for sinking cylinders, and the ingenious reversal of that principle so effectually applied at Rochester bridge; and finally the modifications which the centre pier of Saltash bridge was constructed at a depth of nearly 100 feet. He thought, however, when the necessity arose for similar structures, Mr. Stoney's principle would be found applicable in analogous conditions with great economy. He had the pleasure

of visiting these works a couple of years ago, and could assure Mr. Parkes that "land carriage" was inapplicable at Dublin.

Mr. Vernon Harcourt observed, through the Secretary, that he had been much interested in the description of a work in which the appliances and method of construction were so admirably adapted for carrying out the projected design, and in which great solidity and durability had been attained at a comparatively moderate cost. The Author had referred to the applicability of this system of building with large blocks of concrete to the construction of piers and breakwaters. Mr. Harcourt considered the system might be adopted with advantage in the case of large works, especially in localities where stone was scarce, or when it was requisite to have a road on the structure. No staging would be required, and thus one source of sea damage would be avoided, a solid mass, immovable by the sea, being deposited at one operation. The extremity of the work could also be easily secured by a cross wall of huge blocks, and all chance of injury from unequal settlement would be removed. It was probable that the rate of progress would be greater than the ordinary methods admitted of, as less time ought to be employed in depositing one large block than a number of smaller ones; but he considered the Author was too sanguine in the estimate of the number of possible working days in exposed situations. Though the blocks could be deposited on any one calm day in winter, it would be impossible to proceed with the works in the winter months, as the process of levelling the bottom must be carried out, whether the foundations rested on a rubble mound or on the natural bottom; and even in the summer months there would be many days on which the work of levelling the bottom and depositing blocks could not be attempted. The employment of a diving bell, for the purpose of levelling the bottom, would probably be found inexpedient in exposed situations where there were strong currents. Diving bells had, in the first instance, been made use of at the Alderney Harbour Works; but when the bell was lifted a little off the bottom, the rapid tidal current drove the men against the sides, so that the use of the bell had to be discontinued, and helmet divers exclusively employed. He considered that equal care should be taken to place the blocks close together in a breakwater as in the work described, for the slightest aperture between them would expose their sides to the action of the sea, which, in time, would wear a passage through, and affect the durability of the work.

In carrying out comparatively small works this method would not be advisable, owing to the expense of the requisite plant, and

to the necessity, in addition, on the sea coast, of constructing some place of shelter for the barges. A work on which he was at present engaged, the construction of a harbour at Rosslare, near Wexford, could be most expeditiously executed with the appliances described, as the design consisted of a viaduct, 1,000 feet long, supported on twenty-four concrete piers, the largest of which would only weigh about 220 tons, from which a solid breakwater, 1,000 feet long, was to extend into about 21 feet depth of water, composed of two concrete walls with filling between. The cost, however, of the plant for building with large blocks, and of making a place of shelter for the barges, would swallow up nearly half the capital proposed to be expended. The same objection would apply to most piers and harbours made for trading purposes. In the work just referred to, a similar result, namely, constructing each pier in one block, had been attempted, with scarcely any plant, by depositing concrete *in situ;* but this, though partially successful, had proved, unlike the Author's method, a slow process, as several consecutive days of calm weather were required for erecting the casing and depositing the concrete; and one day of windy weather, from an exposed quarter, damaged the casing, and necessitated the recommencement of the work. Moreover, this system involved a large expenditure of cement, and, unless the casing was carefully closed in at the bottom, an eroding action was liable to occur close to the foundation, tending to undermine the block. With extreme care and ample time, a breakwater might probably be constructed, in shallow water, in one solid mass throughout, by the process of depositing concrete *in situ*, which might compare favourably as to durability with any other system of construction. He considered, however, that in constructing an upright breakwater of concrete, with a moderate outlay on plant, the methods adopted at Aberdeen and at Kurrachee were the most suitable, though to lay down any fixed rules for the construction of marine works would be unwise, considering the varying circumstances under which they had to be carried out. The Author had referred to one instance in which the stone forming the rubble mound of a breakwater tended to travel towards the land. Exactly the same movement occurred at Alderney, where the smaller rounded stones on the surface of the mound were carried towards the shore extremity of the breakwater, and some ultimately round Grosnez Head into the adjoining bay; this result being due to the set of the tide, and the direction of the strongest wind. The wearing action of the sea was not confined to rounding the foreshore stones, but, where the foreshore was high,

the face stones on the seaside of the superstructure, though composed of granite and of the equally hard native Mannez stone, were rounded and almost polished by the constant attrition of the foreshore.

Mr. Stoney said that last year a length of 411 feet of quay wall had been finished. The rate of progress depended almost entirely upon the diving-bell. If there were two diving-bells, the building could go on twice as rapidly as at present. On the previous day a block had been lifted and put down in the afternoon, and the same could be done day after day in a sheltered harbour. In addition to the 411 feet of quay wall completed last year, four large blocks of 140 tons each had been constructed. Two of these were slung together and conveyed 3 miles down the river in December last, and two more a fortnight since. These were for the purpose of protecting a breakwater on the south side of the harbour. The foreshore there was formerly constructed of large blocks of granite weighing from 6 tons downwards, which had been to a great extent comminuted and gradually washed away. Before 1862 there was an annual expenditure of £600 for replacing the foreshore. He accordingly replaced the material washed away by large blocks of 50 tons weight, the cost of which was about £3,000. This protection lasted twelve years, and the annual expenditure of £600 (or what at the present rate of wages would be represented by £900) was saved. One of these blocks, in the winter of 1873, was moved to a distance of 30 feet and turned upside down. He was now putting down 140-ton blocks in order that they might not be displaced. He had stated that the blocks described in the Paper were of 350 tons weight, but he had reason to believe that they were more. The displacement of the floating shears was a little over 7 inches for each 100 tons; and when the block was suspended, and water poured into the tank, the shears went down 54 inches, which would give a weight of nearer 400 tons than 350 tons. Last autumn he had constructed a beacon-tower similar to that described in the Paper, which was carried down with equal success. It weighed a little over 80 tons. It was placed *in situ* and formed its own cofferdam. He might add that, after the floating shears and diving-bell had been contracted for, and to a great extent completed, some of the members of the Ballast Board thought it desirable, in undertaking a work of such a novel character, to obtain the countenance of some additional authority to support them. They accordingly permitted him to consult Mr. Bateman, whose report on the matter in 1865 was too flattering for him to repeat; but it was a great

encouragement in carrying out so novel and arduous an undertaking.

Mr. Parkes, in answer to a question why he had adopted the peculiar form of laying the blocks at Kurrachee, said that the origin of the idea was that of vertical courses, but that would have been practically impossible, because the end course would be liable to topple over seawards, especially when a weight was brought upon it. For that reason they were laid slanting backwards, about 3 inches in the foot. The great object in sea-work was that each block should rest upon a single block below, and have no break of joint. When one block rested upon two, if the foundation was not perfectly solid, there might be an uneven settlement, and then the upper block would rest upon a mere hump, and would rock backwards and forwards. The system, moreover, was found by experience to be rapid in execution, as each block when lowered was guided by the inclined face of the block behind it into its place, and at once took a fair bearing.

Sir John Hawkshaw, Past President, said, he had great pleasure in bearing testimony to the successful mode in which Mr. Stoney had carried out works of a novel and interesting character. About six months ago he had the pleasure of seeing them, and the whole operation appeared to be managed with extraordinary ability. For the situation, he thought the system a successful and appropriate one; but he could not agree that the method was equally applicable to breakwaters generally. This was an instance of generalising from a particular structure, and concluding that it was the best for all possible occasions. Engineering was not so simple as that would seem to indicate. No plan could be laid down which would be everywhere applicable. It was necessary to consider the special circumstances of each case, the material to be dealt with, and the situation where the works were to be carried on. In many instances it would be impossible to apply this method of setting large blocks. He had such cases under his own supervision at the present moment. On the coast of Holland, for instance, the surf was too high to admit going out to sea with such an apparatus during a sufficient number of days in the year. Nor could such a plan be adopted at Holyhead. The reason why the Author had been so successful was, that he was building in a sheltered place, which was practically an inclosed pool. He was inclined to think with Mr. Parkes that there were cases in which the method adopted at Kurrachee would be better. There were also other cases in which even the mounds that it was suggested were only put down to be ultimately destroyed might

be adopted with advantage. At Holyhead, for instance, there was a mountain close at hand to obtain stone from at little cost. At Alderney and at Portland also the mound had been used, because the stone was close at hand, and could easily be thrown into the sea in large quantities, and at comparatively small cost. No doubt these mounds might to some small extent wear away in the course of time; but he knew of no work done by engineers which could be regarded as everlasting. Although a solid wall faced with granite was a more durable structure than a mound of stone on which the sea dashed, and which was liable to be worn away by attrition, unfortunately the cost was vastly greater. The breakwater at Holyhead, which had a central wall, an interior quay wall, and a wide esplanade, cost about £163 per lineal foot, while that at Dover, which had a vertical wall of less average height (51 feet as compared with 66) had cost £345 per lineal foot. Taking the difference of cost, and setting it aside as capital upon which interest was saved, the possible repairs referred to by Mr. Stoney would become a mere bagatelle. By effecting a saving of £300,000 or £400,000 outlay, there was an annual saving of £20,000 a year, and an expenditure of, say £2,000 a year in keeping the structure intact would be trifling in comparison. It was necessary to build a vertical wall at Dover to provide deep-water berths for steamers, but at places like Holyhead, Portland, or Alderney, this method could not be adopted with advantage.

Sir John Coode agreed with Sir John Hawkshaw, both in his admiration of the arrangements made by the Author, and with regard to the impossibility of adopting any plan which should be of universal application. The arrangement of the floating shears was admirably suited to the particular circumstances of the River Liffey. Before making any further remarks, he should be glad to know the number of cubic feet to a ton in the blocks of stone which the Author had built. [Mr. Stoney said he had calculated 14 cubic feet to the ton.] In that case the stone must be remarkably dense. He had himself built blocks of a similar description made with stone of a Silurian character, and their weight was 15·33 cubic feet per ton. With regard to the mode in which the hearting was composed, it was, no doubt, an admirable one for blocks of that character. It was adopted about the same time in some works with which he was professionally connected, at Table Bay, by Mr. A. T. Andrews, M. Inst. C.E., the Resident Engineer, and had proved most successful. This mode of forming the blocks was not adopted for the first time at Dublin. The same method had been employed at Alderney twenty

years ago, as was also the ingenious method of lifting the blocks by T-headed suspended bars. He had greatly admired and used it as being one of the simplest contrivances yet adopted. It was, however, desirable to have a mode of freeing the lewises from the block by some self-acting arrangement which could be worked from the surface of the water, and he thought that would be shortly accomplished. The diving cylinder was an ingenious arrangement, and, no doubt, most suitable to the particular work in question. Curiously enough, an almost identical bell was made in the same year for the work at Table Bay, and was successfully employed by Mr. Andrews. Great credit was due to the Author and his foremen for the remarkable accuracy with which the work had been put together. The cost of the wall was stated to be £40 per lineal foot, but that did not appear to include the first cost of the plant which, in such a work, was a material item. In the case of a wall 1,000 feet long it would add £33 per lineal foot; and in the case of a wall 3,000 feet long the additional cost would be £11 per lineal foot. The cost of the bell work, including maintenance, but not interest on the plant, was said to be about 15*s.* per cubic yard of excavation. That, again, did not include the first cost of the plant. Taking into consideration the large quantity of excavation required, the cost of the plant would in this case add 5*s.* per cubic yard, making the amount 20*s.* It might be objected that it was not fair to take the whole cost of the plant, because it would be of some value when the work was completed. His own experience was no one knew how to use special plant when the particular work was finished. But taking only half the cost of the plant, the 15*s.* was increased to 17*s.* 6*d.* He had excavated large quantities of rock by means of the diving helmet, without the bell, and the cost, including the contractor's profit, varied from 14*s.* 8½*d.* to about 16*s.* In many cases, too, the helmet divers could work when, owing to the agitation of the water, it would be impossible to use the apparatus. That showed that an arrangement which might be very suitable for quiet water like the Liffey, was not economical, or indeed applicable in a sea-way. It had been assumed that if the shears were used for a breakwater only two hundred days in the year a certain amount of work could be done; but it would be a mistake to expect anything like two hundred days' work in the open sea-way. From forty to fifty days, he thought, would be nearer the mark. It was stated in the Paper that works of rubble contained the elements of their own destruction; and the Author said, properly enough, that if the slopes

were paved and the structures protected—that was, if proper and reasonable precautions were used—there was nothing to be apprehended. Reference had been made to several places where material had been swept round the pier-heads and formed dangerous shoals. He was not aware that that had happened to such an extent, and would be glad of the particulars. The Author further stated that, in the case of a vertical wall, if the foundations were secure, and if the stones were massive enough—so bonded together that they could not be destroyed by the action of storms—it would possess the required elements of stability. Granting those assumptions, of course the result could not be denied. In the latter part of the Paper, only one hundred and fifty days' work per annum had been calculated upon; but even that was far too great. One material point appeared to be lost sight of—the effect of the tidal currents. In projecting a work across a bay, the current would necessarily be more or less increased; and to put down two blocks, one over the other, in such a tide-way would, he thought, be a formidable undertaking. It had been stated that Mr. Stoney might be considered as the great pioneer in the construction of hydraulic works in concrete; but he was not entitled to that distinction. "*Palmam qui meruit ferat.*" He believed the credit was due, not to English or to Irish Engineers, but to the French, who had adopted the system of concrete blocks thirty years ago at Algiers. It had likewise been said that the Holyhead and the Portland breakwaters were constructed in almost precisely the same way as that at Alderney. There were, however, material differences between the two first and the last-named structures. He agreed that the plant for blocks, however applicable to large works such as those at Dublin, would be out of place in smaller works. With regard to the mode adopted at Kurrachee, the same system was recommended by Major Askwith, of the Royal Engineers, to the Committee for the construction of a harbour of refuge in Dover Bay, in 1846, and great credit was due to that officer for suggesting that mode of construction. He hoped Mr. Stoney would receive his criticisms in the spirit in which they were made. If their discussions ceased to be critical they would cease to be profitable.

Dr. Pole stated, in corroboration of Sir John Coode's remark as to the early use of concrete for sea works by the French, that he had occasion some twenty years ago to examine, in conjunction with the late Mr. Rendel, the great harbour and dock works then being constructed at Marseilles, and found that concrete was used

there on a large scale. Not only were concrete blocks of great size formed on shore and laid in the breakwater, but, by a most ingenious mode, the same material was deposited in a loose state under water, at a considerable depth, to form quay walls, and the structures thus built were found to have great stability.

Mr. Bateman, Vice-President, said when called upon to advise the Dublin Harbour Board he felt he had a difficult task. He had some hesitation in criticising Mr. Stoney, who, he was quite sure, was better able to instruct him. Mr. Stoney laid before him the whole of the designs, and showed him the results of the experiments made upon concrete blocks, which had been continued for many years. He went through all the calculations, for the purpose of forming a correct opinion upon the proposed work, and he felt constrained in every way to recommend the adoption of the proposed plans, which, he was happy to think, were now drawing to a successful completion. Great credit was due to Mr. Stoney. Other persons had, no doubt, used large concrete blocks, but the Author was entitled to the credit of constructing blocks of anything like 400 tons weight. The blocks referred to at Marseilles weighed only from 13 tons to 16 tons, and their size was 4 feet by 4 feet by 12 feet, or thereabouts. The harbour at Marseilles was a beautiful structure. It was formed entirely by a long mole of concrete blocks cutting off a portion of the Mediterranean from the general sea, within which the docks existed. The concrete blocks were formed, in a somewhat rude manner, of large gravel and hydraulic lime, and were tumbled in at random. They formed a protection one to another by resting upon and jamming each other fast. He did not believe that the sea, although it broke with considerable force against the breakwater, would move any of the blocks. Upon these blocks was raised a heavy parapet wall, which protected the docks from the sea, within which were offices, buildings, a wide roadway or esplanade, and a quay wall. If they were isolated blocks, they would be liable to be moved in a different manner. He agreed in the opinion that every work must be considered with reference to its peculiar circumstances. At Holyhead, Portland, and other places, where there was a large mass of rock behind, although a breakwater was constructed which carried with it the elements of its own destruction, yet that gradual waste might be repaired at a less cost than the interest of the money that would be required to make an indestructible work. It often happened that a cheap construction would encourage the establishment and extension of trade in a manner which would enable the same place afterwards

to construct a better work of more suitable material. Where, however, as in Dublin, there was a river crowded with vessels, in which it would be extremely inconvenient to have a cofferdam, and where the trade was constantly increasing, it was a matter of importance to be able to construct a wall which should not, during its construction, encroach in any way upon the water. That arrangement had been successfully carried out. When he examined the plans he was aware that blocks of 80 tons had been carried into the open sea. It now appeared that two blocks of 140 tons each had been conveyed by the same vessel, and placed in the open sea, in a manner that would probably defy the force of the water, which had previously moved a block of 50 tons. It was astonishing that such a force should be exerted by the water in that situation, and it showed that isolated blocks could scarcely be made too heavy. The experience gained by these arrangements might be usefully applied in many parts of the world. He did not wish to discuss the details of the work, but he should be glad to hear from gentlemen having special experience, any defence of the particular structures which the Author had attacked. It was a sign of the advance of engineering knowledge that blocks of 350 or 400 tons could now be constructed and laid.

Mr. W. Dyce Cay thought the barge unsuitable for building breakwaters, as a slight ground swell or rolling motion would make the setting of large blocks with it a difficult and dangerous operation. He agreed as to the propriety of building breakwaters with blocks of very large size, but the expense of manufacturing them in a blockyard, and carrying them out to the work when solidified, was a great disadvantage. He wished to suggest another method by which, while the advantage of building with large masses was retained, only small weights required to be transported, namely, by building with concrete deposited *in situ* inclosed in large bags. He had deposited a number of bags containing each 100 tons of concrete in the construction of the new breakwater at Aberdeen. These bags were deposited to form an apron along the exposed side of the work. The plant which he would recommend in general for the purpose of depositing bags would be similar to that he had used for depositing bags containing 16 tons of concrete each. This was done by means of a wrought-iron box or skip, the bottom of which opened on hinges like the bottom of a hopper. Into this box was fitted a bag, which was filled with the required weight of concrete, and was then sewn up. The box with its contents, viz., the liquid concrete sewn up in a bag, was

lowered by the cranes to the divers, who by signals guided it into position close above the required site of the bag in the work; a trigger was then pulled, which released the bottom of the box, and the bag was deposited. The whole of the foundations of the Aberdeen breakwater were constructed in that manner. The system possessed great advantages in point of economy and solidity of work, as the expense of the manufacture and transport of heavy blocks was avoided. The accurate levelling of the foundations was also unnecessary, and when deposited the soft bags lay so close to one another, that an almost monolithic mass was obtained. He thought the method applicable to the building of the whole of the submarine part of a breakwater, except perhaps the part just at low water level, where special precautions would have to be taken to prevent the wash of the sea from tearing the bag before the concrete was sufficiently set.

Mr. J. I. Thornycroft said the Author's method had been objected to on the ground of expense. He was indebted to Mr. Rich for an idea which would greatly lessen the cost of the shears for lifting the blocks. It consisted in dispensing with the centre part of the float, which served no useful purpose, but rendered necessary great longitudinal strength. There were several objections to the shears employed. Their stability was dependent on staying the block in the centre of the line of the vessel. It appeared to him that the shears ought to be constructed with the centre of buoyancy as near as possible to the block to be supported; in that way the great balance weight required by the existing shears would be avoided. If the vessel supporting the block were divided into two parts, one alongside the wall being built, and the other also parallel to the wall, but say about four times as far from the centre of the first part as the mass to be carried was from it on the opposite side, the frames of the shears in side elevation would be a simple triangle, shear legs forming a strut down to the supporting float, a strut also to the counter weight, and a tie from this point to the top of the first strut or shears. The barge at the back or second part might contain all the machinery and the heavy parts, and thus the necessity for ballast might almost be avoided. So far as the water in the tank was below the level of the surrounding water, it was supported by the surrounding water, and that part of it, therefore, was almost useless, in fact it added unnecessary bulk, for the water was not carried by the shear legs over it, as appeared to be conveyed in the Paper. By the plan proposed the shears might be greatly reduced in size, and therefore might be more cheaply constructed;

and much greater stability would be obtained. It had been stated that in raising the blocks the entire weight was not lifted by hauling in the chain, but by filling the tank with water, and in that way the strain was equal on every strand of that chain round the blocks. The Author had not remarked, however, that this was not the case in lowering the block, where there would be more strain on the end made fast than on the other end. With regard to the use of the two pairs of tackle to lift the blocks, it appeared to him that one tackle was in danger of getting nearly the entire load.

Mr. Redman said there was some analogy between the Paper under discussion and that read last session by Mr. Milroy,[1] the problem being somewhat similar, to obtain a foundation for a quay wall in a considerable depth of water, without the intervention of a cofferdam. The expedient was certainly a bold one; and he thought the talent and ingenuity displayed in working out the details, in what might almost be termed river engineering, would enable the Author to overcome many of the practical objections raised to the application of the system to submarine structures. It was undoubtedly impossible to apply any fixed rule or classification to harbours. He had attempted to classify lighthouses, but he found great difficulty in doing so, and it was the same with breakwaters and harbours. In the discussion on the Alderney breakwater he had pointed out the great variety existing in the conditions surrounding the national harbours of the country.[2] What appeared to be an exceedingly bold experiment on the shores of the Liffey would be still more hazardous at Plymouth, Cherbourg, or Alderney. Taking the dimensions given by the Author, the weight of each block, according to Mr. Redman's estimate of the material, would be about 312 tons instead of 350 tons. Some interesting information had been furnished with reference to the breakwater at Kurrachee. Any one intimately acquainted with the harbour of Alderney, with its rocky bed 20 fathoms deep, a precipitous shore, and an offing across the Atlantic, would hardly say that a system applied at the head of the Arabian Sea for a long and gradually shelving foreshore, would be applicable there. No analogy existed between the two cases. There was also a liability to error by a comparison of the prices at the shores of the Liffey and at the outlet of the Indus. It appeared, however, that the suggestions contained

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxv., p. 186.

[2] *Ante*, p. 84.

in the Paper were as applicable to a place like Kurrachee as anywhere. If the machinery at Kurrachee were amplified and the blocks made larger, the horizontal cross-joints in the structure would be done away with; and if the blocks were of the entire width of the work, the longitudinal vertical joints might also be done away with, and the action of the water through the work to a certain extent checked. It would be objectionable in many structures to have the water pouring over the top. The settlement that occurred at Kurrachee with entire blocks would be less liable to produce dislocation of the superstructural mass. Any attempt to reduce the cost of the great national breakwaters was worthy of encouragement. A Royal Commission had been sitting upon unseaworthy ships, and the public mind was quite alive to the expediency of the inquiry. It was looked upon as criminal to send vessels to sea that were not thoroughly seaworthy, and the public might hereafter see the necessity for greater protection to seaworthy ships.

Mr. A. T. Andrews remarked that twenty years ago, when engaged in some repairs in the West India Docks, he made large blocks of concrete, of which one-fourth consisted of Kentish rag, which answered very well. In carrying out works at the Cape of Good Hope he had used large blocks in building dock-walls. The funds at his disposal were limited, and he had to employ unskilled Kaffir convict labourers, who, however, in a short time became skilful in constructing concrete walls with large stones. The stones were hard and dense, about 12½ cubic feet to the ton, and no tool could touch them. A bed of moist concrete was made, and the stones were worked into it. The weight of the blocks was from 10 tons to 12 tons. Some heavy walls 40 feet high were built of that material, and the structure was very cheap, considering that the cement had to be imported from England. He had employed the same system of large blocks in order to protect the end of the breakwater. Their weight was about 70 tons, and they were laid just above low water. The sea gradually took them down a slope, and as they moved others were put behind. With the aid of convict labour the cost was from 12*s.* to 18*s.* per cubic yard. Although the labour was free, the cost of superintendence was considerable, so that the expense of labour was not all saved. There was also a large outlay for tools for the convicts.

Mr. J. N. Douglass said it had been stated by the Author that blocks weighing 50 or 60 tons had been moved by the sea in the Bay of Dublin. Unfortunately, there appeared to be no reliable

information as to the maximum weight of blocks of stone capable of being moved by the sea. Such information was, in his opinion, a matter of great importance in the construction of breakwaters. The heaviest seas he had experienced were on the west coast of England, about the Land's End, and the Scilly Islands. In the latter place a piece of rock had been moved weighing over 200 tons, and that not in the most exposed situation. He should expect that in the most exposed part of the coast a block of 300 tons might be disturbed by the heaviest seas. He believed that Mr. Stoney had acted judiciously in adopting blocks of 350 tons, and he agreed with him in the use of such blocks in vertical walls for breakwaters. At the same time he concurred in the views as to the difficulties attending the transporting and placing of such blocks in sea works with the floating appliances used so successfully in the smooth waters of the Liffey. He thought the number of days in which blocks could be safely transported and set in this manner would not approach one hundred and fifty per annum; indeed, in some places where breakwaters were most required, he should consider thirty to forty days, including Sundays, as many as could be relied on. Besides the uncertainty of obtaining smooth water, there would be the further difficulty experienced in mooring the craft, and setting the blocks in the strong tide generally met with at the end of a breakwater carried out from the shore. He should prefer transporting the blocks by land somewhat in the manner adopted at Kurrachee. In that case the blocks were only of 27 tons weight; but heavier machinery of the same description might be successfully adopted. He was of opinion that, with the blocks transported and set in this manner, the work would be carried on with greater regularity, expedition, and economy than by any floating appliances. Large blocks had been used for many years in vertical walls by French engineers, and the blocks had been transported and set in the work by barges, but this was in smooth water as at Dublin. In 1868 he visited Brest, and went over the works of the Port Napoléon, then in progress, where blocks of 150 to 200 tons weight were transported and set in the vertical walls of the work by barges; these works were, however, in sheltered water, and there was little or no tide. The blocks were formed of small rubble in London Portland cement. They were built above the level of high water on trollies, and when ready for the work they were sent down an incline to the level of low water, and the barge or barges were secured to them with the rising tide. They were then

transported to the intended site, and placed in position with the following ebb-tide. He was of opinion that in such a work as that at Brest the admirable floating shears and appliances of Mr. Stoney might be used with success.

Mr. STONEY said he had tested the weight of the blocks by building a smaller block of similar texture, and weighing it on a table. The blocks were composed of rubble, not of concrete. A visit to the works would enable a convincing proof to be given that the blocks were more than 350 tons in weight. The horizontal area of the floating shears was within 7 feet of 6,000 square feet, and the barge went down 54 inches into the water when the block was at one end and the water pumped into the other to balance it. The block, however, was heavier than that would indicate, because when first brought alongside the wharf, the tank end of the shears was considerably deeper in the water than the bow end: there was a difference of 4 or 5 feet; and that, he thought, could not represent less than 30 or 40 tons. Of course, moorings were necessary to hold the vessel in position. When the four blocks of 140 tons were put down, the moorings were laid down the day before where the current was running from 2 to 3 knots an hour. He did not apprehend any difficulty in connection with the current, except that a more powerful tug might be required. What he did fear, however, was the waves; and, as far as his limited experience went in connection with breakwater work, he thought that on those days when the waves exceeded 3 feet in height it was not desirable to use the methods he had adopted. Such waves had occurred when he laid the blocks in December. Two of the blocks were recently deposited immediately before a severe gale broke over the coast of Ireland. It was almost superfluous to remark that he never claimed to be the pioneer in the use of concrete. The merest tyro was aware that concrete was adopted by the French for breakwaters long anterior to its use in England, and he believed it was employed by the Romans long before it was used by the French. An objection had been made to a statement in the Paper that the vertical breakwater would be secure if the individual stones were massive enough, or were so bonded together that they could not be disturbed by the action of storms. But one of the ways in which vertical walls failed was by the reflex action of the waves or impounded air driving out individual stones; and he submitted that blocks of from 300 to 400 tons weight would not be liable to this source of failure. The first notice he had seen of Sir John Coode's diving-

cylinder was in Humber's work on "Modern Engineering,"[1] published in 1868, some years after his own construction had been made. But both Sir John Coode and he had been anticipated by a Frenchman, who took out a patent in 1858 for a similar contrivance, which he discovered after his designs were completed. He believed, however, that this machine was the first instance of a chamber 20 feet square; and it had this advantage over other diving appliances, it afforded a plane surface of 400 square feet which was perfectly calm in rough weather or in currents, and enabled the bottom to be levelled with a degree of accuracy attainable by no other method. If, for example, there was 1 inch in depth of water at one corner of the bell, and ½ inch in the opposite corner, this showed that the bottom required to be excavated ½ inch in the latter to bring it to a horizontal bed. With regard to the cost of the plant, it had been overlooked that he had charged 7 per cent. interest, which would repay the whole amount with interest in twenty-four years. The present works were of great extent; after they were completed others would probably be required. He thought the diving-bell would be useful in harbours for various purposes, such as drawing stumps of piles, or removing rocks and large stones. The block wharf was designed to act as a cofferdam for future graving docks to be constructed inside it, or as a wharf for vessels to berth alongside when not required for building purposes. In considering the question of cost, it should not be forgotten that the wages of all classes of labour had risen enormously within the last few years. He had been asked to refer to cases in which shoals had formed inside harbours. One of these was at Howth, where a shoal, formed a few years ago, was believed to have been produced by débris from the foreshore. A similar occurrence was slowly taking place at Kingstown, where Mr. Barry Gibbons, late Engineer of the Board of Works, had constructed a groin, to prevent the stones from travelling into the mouth of the harbour. The groin was carried away by the action of the waves, and there was no doubt a slow movement of the stones round the pier head and into the harbour. A few years ago he saw a deep valley in the foreshore of the Holyhead breakwater, extending to near low-water level, and a stone wave reaching to near the top of the parapet. Last autumn that stone wave was moved, and he saw that it was much nearer to the end of the pier. The stones

[1] *Vide* "Record of the Progress of Modern Engineering," 1866. By William Humber, Assoc. Inst. C.E., p. 45.

forming the foreshore were nearly all rounded, like an ordinary sea beach, showing the action of attrition. Mr. Vernon Harcourt considered it possible that the diving-bell might not be suitable in currents, because the divers would be swept away. They would not, however, require to work exposed; indeed they were not wet farther up than the ankles, as they never went below the diving-bell, which rested on the bottom. They excavated inside, and when it was lifted off the bottom they sat on benches and were moved along with it. It had been suggested that the mode of construction adopted at Kurrachee was suitable for quay walls; but he was not of that opinion. A "Titan," such as that used at Kurrachee, could not be placed on the top of a quay wall, for the width of the latter at high water level did not exceed 6 feet, which was less than the gauge of the railway on which a "Titan" travelled. In addition to this, the rough surface of concrete blocks, such as those used at Kurrachee, would be totally unfit for ocean ships to lie against in a tidal river where ashlar masonry or fenders were necessary to give the shipping a fair surface to bear against. Besides, the trade of Dublin was extending so fast that it was a great advantage, as soon as 1 foot of quay was completed, to be able to make it available for shipping. That could not be accomplished if a "Titan" were employed in the way described. There was no place for a service ground at the commencement of the new quay, because the existing quays came up to it and were, as well as it, completely occupied with vessels. It had been suggested that the cost of concrete was excessive; and a comparison had been made between its cost in Dublin and that at Kurrachee; but comparisons of prices were apt to be fallacious. The present price of the best Portland cement in London was from 45*s.* to 55*s.* per ton, free on board. The cost of the casks to export it to India was 20*s.* each; the freight was 40*s.*; making collectively 5*l.* 10*s.*, to which was to be added the cost of primage, landing and storing, making in all 5*l.* 15*s.* If the proportions were the same as in Dublin, it would take 19*s.* 2*d.* worth of cement alone per cubic yard of concrete, without taking into consideration the cost of ballast and labour. It was obvious, therefore, that the same result could not now be obtained for 15*s.* The system adopted at Kurrachee commanded great admiration for the purpose for which it was used, but there were certain features connected with it that rendered it not so desirable as might be supposed. In a report by Mr. Parkes in 1872, that gentleman stated that 6 per cent. of the blocks then laid had to be taken up and reset; that one block on the harbour side was driven out by the force of the sea,

and that "after the monsoon it was found that the last block on the sea side had fallen back about 9 inches from the line of that on the harbour side, and this continued, though gradually decreasing in amount, to near the shore. The slight movement of the blocks among themselves had rubbed off some of the little inequalities which had prevented adjoining surfaces from fitting quite closely when first laid, and so enabled each block to fall back upon the one behind it to an infinitesimal extent in any one case, but amounting in the aggregate to 9 inches." .... "The motion of the blocks under the influence of a very moderate swell was clearly discernible after the monsoon. The joint along the centre of the breakwater was seen to open and close with every wave to the extent of $\frac{1}{4}$ of an inch, at a spot immediately over one of the projecting masses of rock in the foundation on which the blocks seemed to hang as on a pivot."[1] Mr. Parkes attributed these movements to the existence of irregular foundations which yielded unequally after the blocks had been laid; but, whatever their cause, he thought they were not calculated to promote the longevity of a breakwater. In place of thirteen or fourteen blocks of 27 tons, one large block on such an uncertain foundation would not have presented the longitudinal joint described, opening and closing by the swell of the sea; nor would there be any such attrition between block and block. Mr. Parkes had also instituted a comparison between the cost of the appliances used at Kurrachee for lifting and setting 27-ton blocks and the floating shears at Dublin, two things rather dissimilar; but in comparing two systems of construction the total cost of the plant in the one case should be contrasted with that in the other; and he found in the report just referred to that the plant at Kurrachee had cost considerably over £20,000.

Mr. Harrison, President, said there could be no doubt that one of the best tests of an Engineer's ability was the ingenuity with which he could adapt the materials at his command to the particular circumstances of the case; and he did not think that it could be said of any two breakwaters that they were in all respects parallel. He believed the use of concrete was one of those things in which English Engineers were far behind the rest of the world. One reason was that they did not possess so perfect an hydraulic mortar as that which existed in the Mediterranean. He had seen piers constructed with it at Trieste, in a depth of 40 feet of water,

[1] *Vide* "Kurrachee Harbour." Report, dated 28th February, 1872, by William Parkes, p. 12.

by forming a casing of planks with piles, in the form of the pier, the interior space being filled in with concrete put down through spouts until it was brought up to the surface of the water. The superstructure of masonry was equal to any he had seen in England.

Mr. R. Gervase Elwes remarked, through the Secretary, that the Engineers, of whom he was one, of the canal now under construction, from the Sutlej River in the Punjâb, early directed their attention to the advisability of employing concrete for the masses of masonry required in the works of art near the head. In addition to a dam 3,700 feet long across the Sutlej River, and the usual locks, regulators, bridges, and escapes, three large 'super-passages,' or over-aqueducts, would convey torrents over the canal, which was 200 feet wide at the bottom, and was intended to discharge 6,000 cubic feet per second. These super-passages varied from 150 feet to 350 feet in width between the head-walls. They would consist of five masonry tunnels side by side, each of 45-feet span, through which the canal water would flow. There was a great dearth of building stone in the district; neither could fuel be obtained in sufficient quantities to burn the immense number of bricks that would be required. On the other hand, shingle and 'kunkur,' or nodular limestone, were abundant. Under these circumstances, Mr. Elwes recommended that the foundations, piers, abutments, and wing-walls of the works of art should be constructed of 'monolithic' concrete *in situ*, and that the arches, at all events of the super-passages, should be built of concrete voussoirs, moulded on the banks, and set in place by a gantry. After some experiments by Mr. Tanner, M. Inst. C.E., which were recorded in the Indian Professional Papers on Civil Engineering,[1] Mr. Elwes, who was then in charge of the construction of a length of 27 miles of the canal, was requested by the Punjâb Government to inspect the Kurrachee Harbour Works, with a view to obtain information regarding the use of concrete in large masses. He accordingly visited the works in the autumn of 1870, and had much pleasure in testifying to the extreme completeness and efficiency of the process there employed, with considerable economy of plant. He was particularly struck with the concrete-mixing apparatus. The revolving boxes had a peculiar angular shape, and their sides were inclined to the axis of rotation. They therefore turned their contents over completely at each revolution, somewhat as mortar was turned over with a shovel, while a cant sideways was at the

[1] *Vide* vol. vii., p. 274.

same moment given to the mass. These combined movements effected a more thorough and rapid mixing, with less expenditure of power, than could be produced by any other form of apparatus he had seen. An ordinary motion of rotation, as, for instance, in a horizontal revolving barrel, tended to separate the heavier particles, while the use of knives or blades, as in a pug-mill, or as in the machine described in the Paper, caused great friction and loss of power, especially where, as at Kurrachee, rubble of considerable size was used as ballast. This inspection of the Kurrachee works confirmed his opinion as to the desirability of using concrete in mass for many of the works on the Sirhind Canal; but no final decision had been arrived at when he left the Punjâb. It might be useful to mention a simple and economical method of mixing concrete, which he had used in large bridges, where mixing machinery was not available. A long, narrow trough, lined with bricks, was provided, the axis pointing towards the spot where the concrete was to be used. At the more distant end there were two tanks for mixing the mortar separately, one being filled and mixed while the other was being emptied. The ballast was stacked close by, and the materials were continually cast into the end of the trough in the proper proportions by measure. As fast as the stuff was thrown in, it was shovelled along, by men stationed at the sides of the trough, to the other end, whence the concrete, thoroughly mixed in its passage, was taken out and carried to its place in the work. The advantages of this method were considerable, as compared with the common mode of throwing the materials in a heap, and turning them over till supposed to be mixed. The labour required was much less, the mixing thorough and equal throughout, the supply continuous, and the concrete consequently fresh. No doubt some reason existed, though not apparent, for the absence of bond in the Kurrachee breakwater. Consisting as it did of nine horizontal prisms, laid in three courses of three prisms each, the prisms themselves made up of blocks set up on end face to face, it seemed to Mr. Elwes, on visiting the breakwater, that a slight alteration in the dimensions of the blocks, to allow them to be laid 'header and stretcher' fashion, breaking joint in the successive courses, would have bonded the prisms together, and have added to the stability of the work, especially in the event of any disturbance in the rubble substructure.

Lieut.-Colonel Playfair, Consul-General, in a communication to the Board of Trade, dated Algiers, 8th November, 1869, said:—

"While I was in the act of penning my annual report, and describing

the splendid harbour recently completed at Oran, containing an outer port of 24, and an inner basin of 4 hectares, 740 metres of breakwater, and 300 metres of quay, I received a despatch from the Vice-Consul there, containing the particulars of a frightful storm which burst over that neighbourhood on the 1st instant, and utterly destroyed all the great works which had been accomplished. On the 30th and 31st ultimo a strong northerly wind and heavy sea set in, but no serious damage was done till Monday the 1st instant. At 11 o'clock on that day the wind increased in violence, the sea, dashing in white foam over the breakwater, entered even the inner basin, and speedily scattered the immense blocks of concrete of which the jetty was composed, leaving not one standing on the other. Not only does the Port of Oran now offer no shelter for shipping, but the débris of the breakwater constitutes a source of actual danger, which vessels will do well to avoid."

February 17, 1874.

THOMAS E. HARRISON, President,
in the Chair.

The discussion upon the Paper, No. 1,376, "On the Construction of Harbour and Marine Works with Artificial Blocks of Large Size," by Mr. B. B. Stoney, was continued throughout the evening.

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